Australian Government

MURRAY–DARLING BASIN AUTHORITY

River Murray from Yarrawonga Weir to Wakool Junction reach report

Constraints Management Strategy

Final Report - July 2015

Published by the Murray–Darling Basin Authority

Postal Address: GPO Box 1801, Canberra ACT 2601
Telephone: (02) 6279 0100 international + 61 2 6279 0100
Facsimile: (02) 6248 8053 international + 61 2 6248 8053
Email: engagement@mdba.gov.au
Internet: www.mdba.gov.au

ISBN (online): 978-1-925221-11-4

Cover image: Gwynnes Creek, a significant ephemeral creek in the Edward-Wakool system. (Photo by Emma Wilson)

Edited by Biotext, Canberra.

Disclaimer

Accessibility

Australian Government departments and agencies are required by the *Disability Discrimination Act 1992* (Cwlth) to ensure that information and services can be accessed by people with disabilities. If you encounter accessibility difficulties or the information you require is in a format that you cannot access, please contact us.

Acknowledgement of the Traditional Owners of the mid-Murray/Mile and Edward/Kolety–Wakool waterways

MDBA acknowledges and pays its respects to the Yorta Yorta, Wamba Wamba and Perrepa Perrepa people. MDBA recognises and acknowledges that the Traditional Owners and their Nations have a deep cultural, social, environmental, spiritual and economic connection to their lands and waters. MDBA understands the need for recognition of Traditional Owners' knowledge and cultural values.

Contents

Summary

For the past century, the Murray–Darling Basin (the Basin) has been developed with a focus on delivering water for productive use. Large dams have been built to capture and store as much water as possible to be used later for consumption and irrigation. There have also been many rules put in place across the Basin around how the rivers and dams are managed.

These structures and practices are of great benefit to our industries and have greatly supported the building of our nation, our Basin communities and our economy. However, the changes we have made have affected how, when and where the Basin's rivers flow and how healthy they are. Water that once flowed downstream is now often stored, and delivered in regular patterns at times that suits production, not necessarily in a more natural variable way that most benefits and supports the environment. Only when dams are full and spill over are there any significant overbank flows downstream.

For many floodplain areas of the Basin, the time between drinks is now too long for floodplain plants and animals. Small overbank flows that connect the river to its floodplain are vital to the environment. These overbank flows improve water and soil quality, recharge groundwater, and support native plant and animal species. Before rivers were regulated, these flows were far more common. The lack of these flows is affecting long-term river and floodplain health, and, ultimately, Basin communities and businesses that rely on healthy waterways.

Environmental watering has been successfully done for many years in some parts of the Basin, and is one way we can deliver water to benefit the environment. However, there would be many environmental benefits if we could deliver slightly higher flows in the future (mostly up to minor

flood level) to reach the floodplains. So, the Basin governments requested that the Basin Plan include a Constraints Management Strategy (the Strategy) to explore how this might be done.

This report investigates constraints to environmental flows in the Yarrawonga Weir to Wakool Junction Reach and was released for public comment in December 2014. Since then, we have continued discussing constraints with communities that might be affected by any changes. This final version contains some new information that communities thought should be included to tell a more complete story of constraints.

The Constraints Management Strategy

The Strategy is about ensuring that water can flow onto the floodplain, while mitigating any effects this water may have on property and people.

For the purpose of the Strategy, constraints are river rules, practices and structures that restrict or limit the volume and/or timing of regulated water delivery through the river system. Implementing the Strategy will support governments to operate our highly regulated rivers in smarter ways to increase the frequency and duration of small overbank flows to sustain and improve floodplain health.

Given consumption and irrigation needs, it is not possible, nor is it the goal, to return regulated rivers to their ‘natural’ or ‘without development’ flows. The Strategy is also not trying to create or change how often damaging major floods occur. The idea is to make modest regulated releases from storages, generally when higher flows downstream would have occurred if dams were not there. That is, the small overbank flows being proposed will ‘top-up’ natural rainfall or unregulated tributary flows, to increase either their peak or duration.

In 2014, we completed the first phase of work — the prefeasibility phase — which involved looking at seven areas of the Basin in more detail. The Murray–Darling Basin Authority (MDBA) collected information about how small to mid-sized flows, up to minor and moderate flood level in some areas, affect the environment and people who live and work along this reach. We also collected information about how such flows can be managed, and what sorts of protective measures are needed first.

The Yarrawonga Weir to Wakool Junction reach

The Yarrawonga Weir to Wakool Junction reach is one of seven areas of the Basin that the MDBA is studying for the Strategy.

The Yarrawonga Weir to Wakool Junction reach incorporates the River Murray channel (sometimes referred to as the mid-Murray) and the Edward–Wakool river system in New South Wales. This reach starts at Yarrawonga and includes all of the River Murray to Wakool Junction. It also takes in the Edward–Wakool system, and the associated rivers and creeks right through to the Wakool Junction.

Aboriginal people have been managing the natural resources of the Basin and the waterways in this region for many thousands of years. Aboriginal culture and the environment are intimately linked, with many species of plant and animal, as well as many features across the landscape, being extremely significant. The local waterways and forests continue to play a significant role for Traditional Owners.

More than 60,000 people live throughout the reach. Land use across the Murray region is now dominated by agriculture, with more than 1,700,000 ha of land dedicated to dryland farming and more than 300,000 ha dedicated to irrigated agriculture. Water for irrigated agriculture makes a significant contribution to the regional economy. Irrigated agriculture is supported by one of the largest privately owned and managed irrigation networks in Australia, delivering water through a vast network of gravity-fed channels to hundreds of agricultural enterprises.

There is little topographic relief in this region, and the landscape can be best described as a broad flat floodplain interconnected through a network of flood runners and creeks. As a result, the hydrology is complex, and large flow or flood events can be highly variable with 'no two floods being the same'. This is partly influenced by the fact that in-flows can come from a number of sources — the upper Murray and Billabong Creek in New South Wales, as well as the Kiewa, Ovens, Goulburn, Campaspe, Loddon and Avoca rivers in Victoria. The complex nature of interconnecting creeks and flood runners within the Edward–Wakool system also contribute to this flow variability.

The environment

This reach contains important breeding habitats for native birds and fish populations, as well as linkages for migratory and nomadic birds and small mammals moving throughout the landscape. The Edward–Wakool played a crucial role in providing refuges for native fish, frogs and birds during the millennium drought from the late 1999s to 2010, and helped the post-drought recovery of numerous species. A number of internationally significant floodplain forests are located within this reach, as well as almost 4,000 additional permanent and ephemeral wetlands associated with the floodplain rivers and creeks.

Both the River Murray and the Edward–Wakool river systems are heavily managed, with up to 87% of the total inflows into Dartmouth and Hume dams being stored for later use. This has changed the local and regional hydrology. River regulation has resulted in less flow variability, reduced frequency of floods, reduced areas of flooding, and flows occurring in spring–summer rather than winter–spring. Small and mid-sized flows that once connected the rivers and creeks to the floodplain are now captured in dams. This has reduced the 'time between drinks' for the environment, as well as the timing and duration of flows for many creeks and wetlands. Another consequence of reducing the frequency and duration of small to mid-sized flow events is that many of the wetlands that are away from the river channel or higher on the floodplain are stranded. As a result, some of the animals that once used these areas are disappearing and the native plant communities are changing.

The Basin Plan aims to recover water for the environment; the Strategy is helping to understand how we can improve the frequency, duration and timing of flow events and increase the current regulated flow rates.

There is increasing interest from communities in this reach to increase native fish populations, and to improve the health of wetlands, rivers and ephemeral creeks (i.e. those that have wet and dry phases) and water quality. Landholders have worked with local agencies to understand more about soil and salinity issues, local wildlife and their habitats, and how they can encourage native species onto their land. Landholders have also been working with environmental water holders to deliver water to wetlands located on private property and ephemeral creek systems using both landholder, State Water Corporation and Murray Irrigation Limited infrastructure.

The Strategy in the reach

Community members are sensitive to natural resource management reform initiatives that affect them, and have expressed concern about processes that lack transparency and are inequitable. Improved transparency, equity and access to participation in decision-making processes will be paramount to ensuring meaningful involvement in future projects for the Strategy.

The MDBA's work in developing the Strategy in the reach is trying to understand the effects of increased flows on private and public assets. This prefeasibility study collected information and data from local communities, councils and other organisations. Results from the prefeasibility study show that private and public assets are potentially affected at flows below the Tocumwal 'minor flood level'. Specific flow rates that were investigated during 2013–14 included 20,000, 35,000, 50,000 and 77,000 ML/day based on flow recorded at the Tocumwal gauge. Flood mapping and community discussions for downstream waterways were based on a network of related flows at downstream gauges.

In late December 2014, Basin governments refined the flow limits that would continue to be considered in Constraint investigations based on the information collected during the pre-feasibility stage. Basin Governments considered the information collected in 2014 and decided to continue investigations of flows of 50,000 and 65,000 ML/day at Tocumwal. This decision was based on a number of factors including feedback from the community members regarding third party impacts, cost estimates for addressing third party impacts and diminishing returns of local environmental benefits from the highest flow rates investigated.

This report presents information collected regarding the previous upper limit of 77,000 ML/day at Tocumwal. This information provided the basis for the decision to reduce the upper limit for further investigations to 65,000 ML/day at Tocumwal.

The community

This reach report reflects preliminary technical work and information collected from the community throughout 2013–14 about the effects of higher regulated flows.

Initially, a draft report was published on the MDBA website on 18 December 2014, and was also emailed and/or posted to stakeholders that had been involved in previous conversations with MDBA about constraints throughout 2013–14.

Several meeting were held between 4-5 February 2015 in Deniliquin, Barham and Moulamein to discuss the draft report. The meetings were attended by about 50 people. The revisions in this final report reflect the comments made by key stakeholders at that time and submissions received by the MDBA.

Prior to this reports initial publication on the MDBA website in 2014, a series of meetings were held with a representative group of potentially affected landholders — the Edward–Wakool Constraints Advisory Group — local government councils, regional and state government agencies, private corporations, and irrigation companies. The MDBA also held local targeted meetings with landholders to seek specific views about different river/creek systems and about the Strategy in general.

A round of community discussions were aided by the MDBA developing maps of broad-scale assessments of indicative flow or flood footprints, and the results of a desktop assessment of potential effects. The community indicated that these maps did not necessarily reflect the extent of inundation they had experienced historically from the flows they were based on.

Further comment was made that landholders were unable to provide informed and definitive comment on the potential impacts on their lives and businesses without knowing the timing, duration, predictability and frequency of these events. The community understood the scale of the mapping was indicative only and was not designed to provide assessment of impacts on specific landholdings.

Following reviews of this information, participants also shared their views about the potential effects of increased regulated flows including:

- increased risk of damaging uncontrolled flood events, both during delivery and following a delivery event through 'wetting-up' of the floodplain
- competition for channel share — consumptive or production water
- interrupted or impeded access to land — isolating stock and preventing crop management
- overland flooding — significantly alter current land-use activity
- floodplain management planning — may limit activities in floodways
- frequency, timing and duration of proposed flows — critical to understanding effects
- managing access during emergencies — bushfires
- potential for environmental damage — increases in pest species, riverbank erosion, tree loss and siltation/sedimentation
- groundwater recharge — increased salinity risk
- devaluation of private land asset
- public and private infrastructure — effects on bridges, buildings and pumps
- tourism — frustrated river access, uncertainty in holiday planning, increased exposure to mosquitoes and sandflies
- adequacy of funding — dividing community, transparency and clarity of processes
- environmental watering — improved communication
- Uncertainty regarding the benefits to local and downstream environments of increasing flows.

The community strongly reinforced the need for local involvement in this, and future work to maximise positive outcomes from environmental flows while making sure that third party effects were identified and minimised. This would ensure that local knowledge is applied where relevant and would reduce the likelihood of adverse risks. Further, the community supported the notion of 'localism' in all aspects of the development of the Strategy.

There was a broad range of views presented across the range of stakeholders about the work being done through the Strategy. Overall, parts of the community were generally supportive of what the Strategy was trying to achieve; however, there were very strong concerns about increased flooding risk associated with all flow rates being examined, with the flow of 77,000 ML/day considered unachievable. Local trials have indicated effects already occur at flows above 18,000 ML/day at Tocumwal. The community recognises the value of providing water to wetlands and to support aquatic wildlife, and has a long history of participating in such programs. However, there is a belief that the flat landscape combined and complex hydrology would combine to increase the risk of third party impacts at the flow rates being examined.

Community members recognise that the impacts of higher flows will be influenced by how often, how long and at what time of year increased regulated flows were likely to occur. As the MDBA was not able to supply accurate information on the likely flows, landholders were only able to provide a general idea of the potential effects at each of the flow rates being examined. Clarity of frequency, timing, duration and predictability is important for landholders, as it will enable more accurate descriptions of potential effects, while also defining areas for further investigation beyond 2014.

Disused bridge in Wakool Shire showing bypass track in foreground. ***Photo: Terry Korodaj, MDBA.***

Benefits, impacts and risks

The ability to deliver small overbank flows relies on governments being able to understand and mitigate impacts on private land, public infrastructure and other activities along the entire flow path. Consultation with the community, councils, and other stakeholders has identified a number of benefits, impacts and risks of implementing the Strategy which are described below. It is important to remember that overbank flows can affect different areas in different ways.

Expected benefits of addressing constraints to environmental watering

General

- Increased riverine productivity (See section connecting rivers to their floodplains)
- Improved soil and water quality
- Increased resilience in riverine systems – the capacity for the landscape to recover after droughts or floods
- Recreational, aesthetic and amenity benefits
- Benefits to businesses that directly depend on healthy rivers and floodplains
- Reduction in black water events due to regular removal of organic matter from the floodplain
- Increased fish breeding for whole of river recreational fishing benefits
- Improved efficiency of environmental water use
- Ecological benefits in the whole of River Murray system

Private property

- Pasture benefits from short durations of flooding (less than 1 week), although this is dependent on the type of pasture
- Soil improvements due to deposition of silt
- Regeneration of vegetation used as shelter by stock
- Flushing of deep saline pools, improving water quality
- Improved capacity to deal with already occurring minor floods due to easements and/or infrastructure upgrades (stock crossings, on-farm access roads, improvements to drainage)
- Filling up creeks and wetlands on private property for amenity and production values
- Watering of forests to increase production of timber for ecological and commercial benefits.

Public infrastructure

- Improved capacity to deal with minor floods by investing in infrastructure upgrades (e.g. roads, bridges, stormwater)
- Addressing flood 'problem areas' and fixing up long standing infrastructure issues (e.g. areas with frequent road or bridge closures, uncontrolled nuisance flooding)
- Improvements to the stream gauging network
- Improvements to strengthen rural levees and bring them up to a minimum standard of protection

Potential impacts

General

- Bank erosion and tree fall during high flows
- Levee bank damage and subsequent maintenance
- Carp breeding and vermin control
- Spread of weeds
- Interruption to recreational activities
- Increased recharge of saline groundwater
- Potential for increased subsequent flood risk
- Potential for increased channel share competition

Private property

- Restriction of access and inundation/damage to infrastructure such as crossings, roads, low-level weirs, pumps, fences
  - Pastures/cropping impacts such as damage to pastures from extended inundation (greater than 1 week),
- Clean up
  - Increased time and costs spent on general clean up after flood e.g. clean up logs, fences, clean out troughs, non-compostable rubbish and debris.
  - Increase in costs and effort of controlling weeds and native saplings
- Stock issues

- Loss of production due to stock exclusion from inundated areas, including time after the area has drained
- Increased time and resources spent moving stock
- Risk of stock loss at certain times of year (lambs, calves)
- Cost of additional feed or agistment
- Fragmentation of paddocks and effects on stock management
- Increased stocking rates on higher ground and therefore depleted pastures elsewhere on property

Public infrastructure

- Inundation of low lying roads and bridges
- Damage to crossings or access roads
- Storm water drainage backing-up
- Access to river-beaches, camping, and boat ramps may be impeded

Potential ways to mitigate impacts

General

- Upgrades to river operation models, and gauging network
- Slowly building up higher flow rates over time to increase understanding (i.e. trials) and
- Improved information systems to provide advanced flow advice and warning
- River health program that targets controlling riverbank erosion

Private property

- Easements, or other landholder agreements, to pay in advance for future managed flow impacts
- Upgrades to on-farm roads, bridges, crossings and drainage
- Upgrades to other on-farm infrastructure (e.g. pump house location)

Public infrastructure

- Road and bridge upgrades
- Levee upgrades
- Levee outlet infrastructure upgrades

Results of pre-feasibility

Flow rates below 50,000 ML/day at Tocumwal are contained wholly within the floodway network. Flows between 20,000 and 35,000 ML/day were generally contained within the channels of creeks and rivers, except for floodplain forests and wetlands, and a small section along the Niemur River. At 50,000 ML/day, overland flows into flood country were evident in a number of places. Flows of 77,000 ML/day showed overland flows in a number of areas across the reach. At this flow rate, 13% of land affected was outside the recognised floodway network.

Similarly, increasing levels of flows lead to increasing levels of environmental benefit for the Yarrawonga Weir to Wakool Junction reach. For example, flows of 20,000 ML/day at Tocumwal would reach approximately 20,000 ha of waterways and wetlands in the reach, 35,000 ML/day would cover around 37,000 ha, 50,000 ML/d would cover 43,000 ha and 77,000 ML/day would cover more than 50,000 ha.

When considered at both the reach and Basin scale, results from this prefeasibility assessment indicate that at flows of:

- 20,000 and 35,000 ML/day (Tocumwal) — would be beneficial, based on the, environmental benefits gained within channel, the likely costs associated with putting in place adequate mitigation measures and the social acceptability of risk management.
- 50,000 ML/day (Tocumwal) — would be more beneficial and mitigation costs were estimated to be reasonable, however, further work is required to build community confidence in mitigating flood risk. Ifcommunity support was raised, investment would justify the environmental benefits gained in-channel and overbank for parts of the reach.
- 77,000 ML/day (Tocumwal) — are socially unacceptable due to the perceived increase in flood risk of delivering regulated flows at this rate. Environmental benefits are considerable at both the reach and the Basin-scale, however, the likely mitigation costs may not justify the environmental benefits gained. On this basis, Basin governments revised the upper flow limit to be considered to be 65,000 ML/day for any future investigations.

This document and additional information

The key aims of this report are to:

- provide a context and background to the work on constraints investigations
- outline the types of impacts and associated mitigation measures and other changes that would be needed to achieve the river flows being investigated
- report on community feedback to possible changes to managed river flows
- identify areas requiring further information
- provide base information for developing a Constraints Measure Business Case to inform a decision by Basin ministers by mid-2016 of what changes to managed river flows are feasible to pursue to the implementation phase (see ‘Next steps’).

Acknowledgments

The MDBA would like to acknowledge the important contribution of knowledge, time and effort provided by the members of the Edward–Wakool Constraints Advisory Group and members of the communities that participated in this project. Landholders in particular, generously provided their time to travel and attend meetings (often at night) as well as considering written materials in the development of this report.

Next steps

This is the start of a 10-year process, and Basin governments are only at the early stages of finding out what the issues and opportunities are, to support future decision making.

Reach reports for all seven regions were released on the MDBA website through October–December 2014. Discussions with community on these reports continued in 2015 to add to our knowledge base and refine our understanding of what flows mean for communities.

Information used to draft the reach reports from all seven priority areas of the Basin was included and compared in the Constraints Management Strategy annual report, which made recommendations to Basin governments about options for further investigations. The annual report is available on the MDBA website.

In late 2014, Ministers decided to continue investigations in all of the seven priority areas. Further to this, Basin governments refined the flow limits that should be considered in future investigations. In the Yarrawonga Weir to Wakool Junction reach, it was decided that 65,000 ML/day would be the upper limit for further investigations in 2015.

Any further work will depend on the decisions of Basin governments. The first decision, in late 2014, was to proceed with collecting more information. This means beginning detailed planning, technical and community studies to better understand the feasibility of overbank flows and the mitigation measures needed for delivering the proposed flows. The 2014 decision is not a green light to build, do or change anything about how the river is managed.

The second decision, in 2016, is about whether to start putting mitigation measures in place, based on recommendations from further studies conducted in 2015. Actions would take place between 2016 and 2024 to ensure mitigation measures are in place — such as formal arrangements with landholders, rule or management practice changes, asset protection and infrastructure upgrades — before any managed overbank flows are delivered.

Wakool River, just downstream of the Noorong Creek junction. ***Photo: Phil Townsend, MDBA.***

What is the Constraints Management Strategy?

At a glance

The Constraints Management Strategy looks at ways to allow rivers to connect to their floodplains more often to improve and maintain the environment, while avoiding, managing or mitigating effects on local communities and industries.

In a river, 'constraints' are the things that stop water from reaching some areas.

The constraints can be:

- physical structures, such as bridges, roads or outlet works
- river management practices.

The Constraints Management Strategy (the Strategy) is about ensuring that our rivers — and the environments and communities they support — stay healthy and sustainable.

In particular, it is about investigating how to connect rivers with their floodplains more often, while avoiding, managing or mitigating effects to local communities and industries.

By carefully managing constraints, we can ensure that water continues to sustain our vital river environments and communities, both now and in the future.

What areas are being looked at

The Strategy is looking at seven areas of the Murray–Darling Basin (Figure 1). These areas were chosen because we are likely to get the best environmental benefits by changing constraints to increase regulated flows in these areas. The areas are:

- Hume Dam to Yarrawonga Weir
- Yarrawonga Weir to Wakool Junction
- Goulburn
- Murrumbidgee
- Lower Darling
- River Murray in South Australia
- Gwydir region.

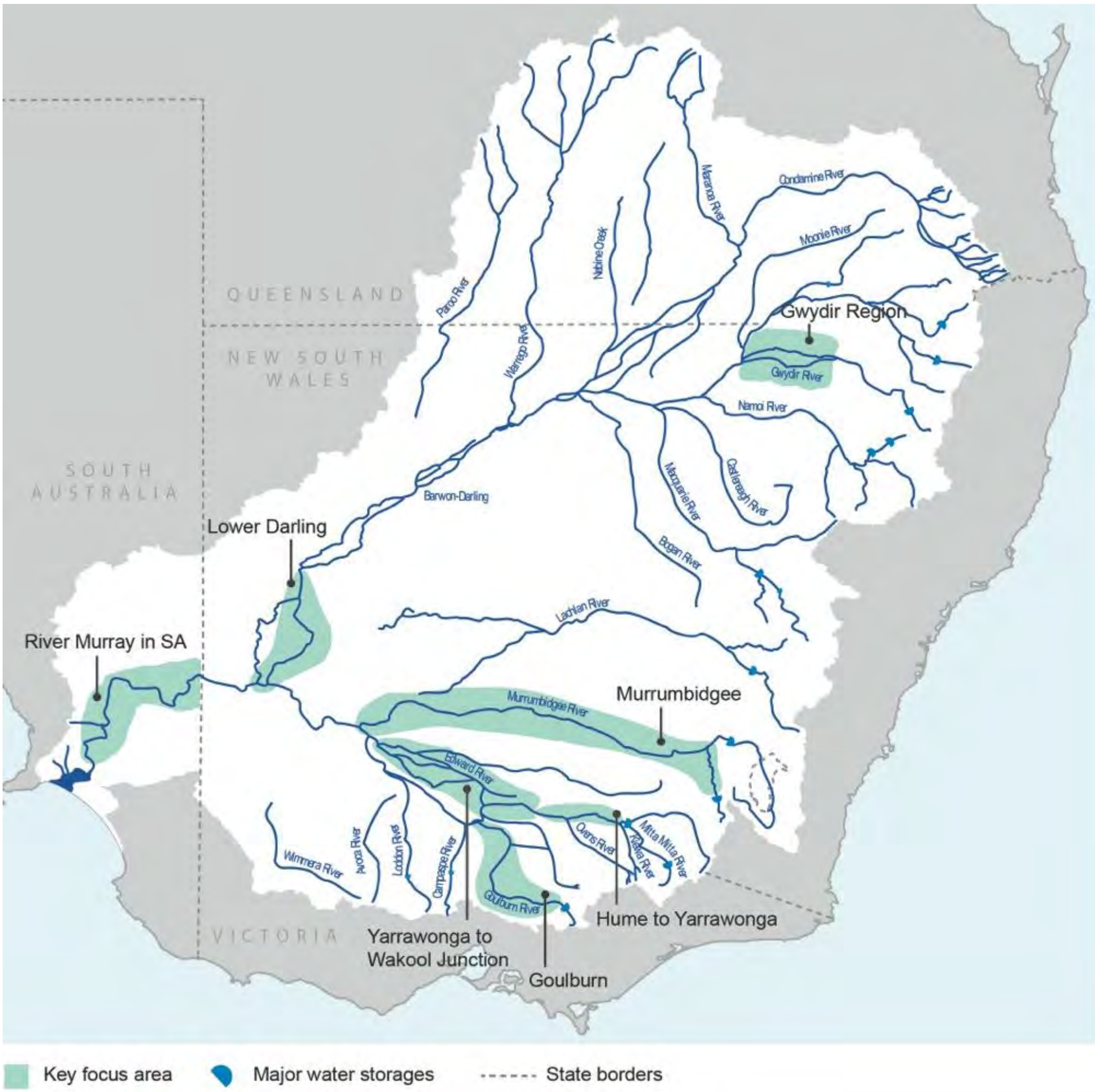


Figure 1: Areas in the Murray–Darling Basin affected by the Constraints Management Strategy

What could change

Current situation:

- The current regulated operation of the river system provides flows within a range that is largely governed by irrigation requirements and minimum flow provisions.
- Irrigation requirements generally follow crop demand patterns and do not vary significantly during the summer irrigation season.
- Rivers are operated to maximise water availability for consumptive use and to limit evaporation losses on floodplains.
- Releases from storages resulting in overbank flows are a consequence of managing storages when they are close to full or spilling over, rather than to meet environmental objectives.

Over time, such operations have led to a decline in floodplain health across the Basin, in some locations this decline has been quite substantial. The Strategy is about identifying and enabling smarter ways to manage rivers so that water availability is still maximised and damage from large floods is limited, but also so that some of the smaller overbank flows that are essential for floodplain health are reinstated.

The environment is a relatively new ‘customer’ for regulated water delivery and has different water requirements — including timing and amounts — compared to cropping. This is why the Murray–Darling Basin Authority (MDBA) is trying to determine if there are ways to increase flexibility in the range of regulated flows that can be delivered to meet the needs of this new customer.

Possible future situation:

Future ways of operating rivers will need to integrate water delivery for a number of different customers. Delivery of water to meet environmental objectives is likely to take advantage of flows from unregulated tributaries that may be topped-up with regulated releases from storages. Together, these sources of water would combine to become a flow of sufficient size to result in small overbank flows downstream. Small overbank flows may be used to reach particular parts of the floodplain to achieve specific ecological outcomes.

The ability to do this relies on river managers having hydrological information that is accurate enough to enable them to plan, with confidence, when and when not to make regulated releases. It also relies on governments being able to understand and mitigate any impacts on private land and community assets along the entire flow path.

Mitigation measures must be in place before regulated overbank flows can be delivered. These may include formal arrangements with landholders, rule or management practice changes, asset protection, and infrastructure upgrades. The Strategy is focusing on these types of activities during the next decade.

It is important to note that the Strategy should not increase how often damaging floods occur.

Small to mid-sized flows

In unregulated river systems, overbank flows occur frequently, wetting the floodplain areas around the river.

The changes being investigated in the Constraints Management Strategy aim to increase the frequency and duration of both in-channel flows and some small overbank flows, allowing water to reach particular parts of the landscape that haven't been getting water as often as they need, such as creeks, flood runners, wetlands and floodplain vegetation.

The flows being investigated are those that could be expected to generally cause inconvenience. Low-lying areas next to rivers and creeks start to get wet, requiring the removal of stock and equipment. Minor roads may be closed and low-level bridges submerged.

The Strategy is about delivering small overbank flows, which are below levels that are damaging (Appendix 1 Flow rates being examined for the reach). Governments understand that some of the flows being investigated by the Constraints Management Strategy will affect businesses and the community, and that these effects need to be mitigated before any flows can be delivered.

The overbank flows would be created by 'topping-up' unregulated tributary flows with releases from storage to increase the peak or duration of a flow event, and so reinstate some of the flows that have been intercepted and stored by dams.

Background to the Strategy

The Strategy was developed in 2013 through technical assessments and many conversations with local communities and industries. It incorporated community views and suggestions from a public comment period in October 2013 (see 'What does the community think?' and the Constraints Management Strategy public feedback report[1]).

The Strategy is part of the implementation of the Murray–Darling Basin Plan.

The Australian Government has committed $200 million to carry out constraints investigations and to fund any approved mitigation works that are identified as priorities by the Basin states in the next 10 years.

1 www.mdba.gov.au/sites/default/files/CMS-Public-Feedback-Report.pdf

Why is the Strategy important?

At a glance

Connecting rivers to their floodplains sustains the local environment and provides benefits to communities, such as improved soil and water quality. River development and regulation have disconnected creeks and wetlands, and reduced the overbank flows that provide this connection.

Assessments in this part of the River Murray and the Edward–Wakool system have identified the need to improve the health of some of the waterways.

River operators currently have very little flexibility in delivering water due to physical and river management constraints.

The Constraints Management Strategy aims to put back some water to the environment to boost riverine productivity, and increase the health and resilience of native plants and animals.

Rivers before and after river regulation

In unregulated river systems, there are no constraints to overbank flows caused by high rainfall and catchment run-off, which regularly spread out across the floodplain and reach floodplain creeks, wetlands and billabongs.

In regulated river systems, dams and weirs harvest water and control high rainfall events, significantly reducing the flow downriver. Regulation aims to maintain some level of base flow in major waterways all year round, preventing the system from entering a drying phase. Levee banks and other impediments to flow have also been constructed in many areas that prevent water spreading out across the floodplain (Figure 3).

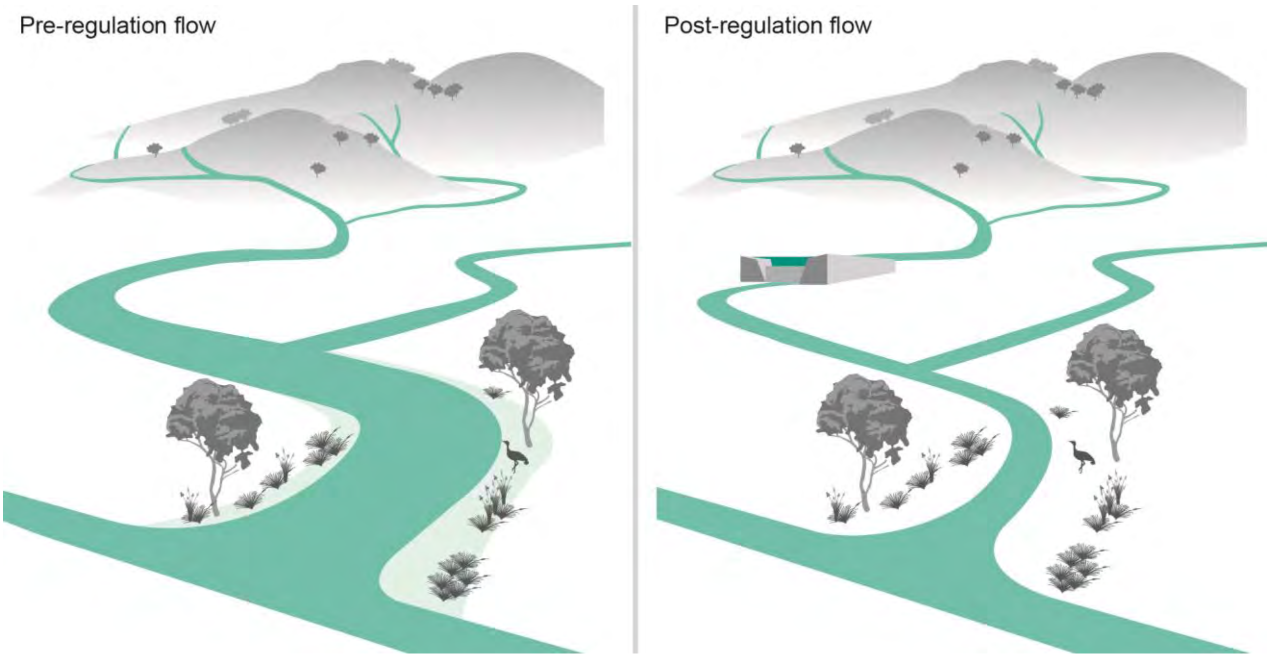


Figure 3: Rivers with pre-regulation and post-regulation flow

This affects the behaviour of the river downstream. It reduces the height and duration of small overbank flows, and increases the time between overbank flows (Figure 4).

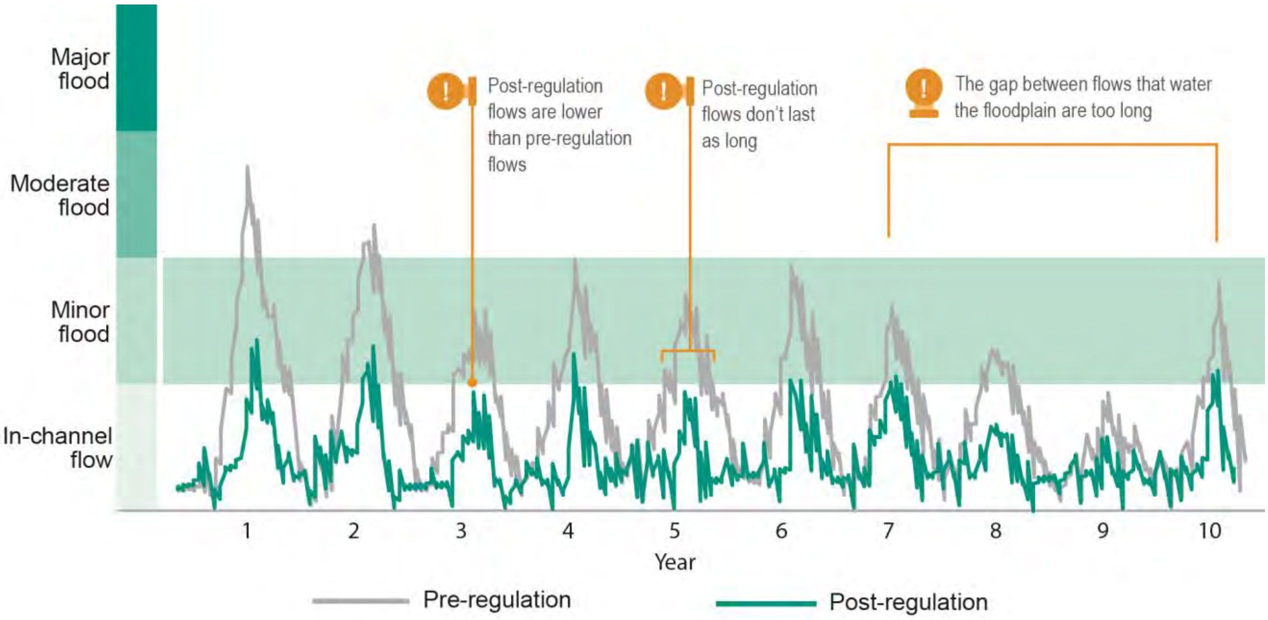


Figure 4: Changes to a river's hydrology after river regulation (hypothetical flow curve used to demonstrate concept)

Regulated releases from storage are mostly restricted to in-channel flows (Figure 5). This reduces the water that reaches particular parts of the landscape — most notably the floodplain and its creek network, wetlands and flood runners. River water stimulates the ecology of many plant and animal species, and without flows to trigger a range of ecological processes (feeding, breeding, moving), both the diversity of species and their individual numbers have declined.

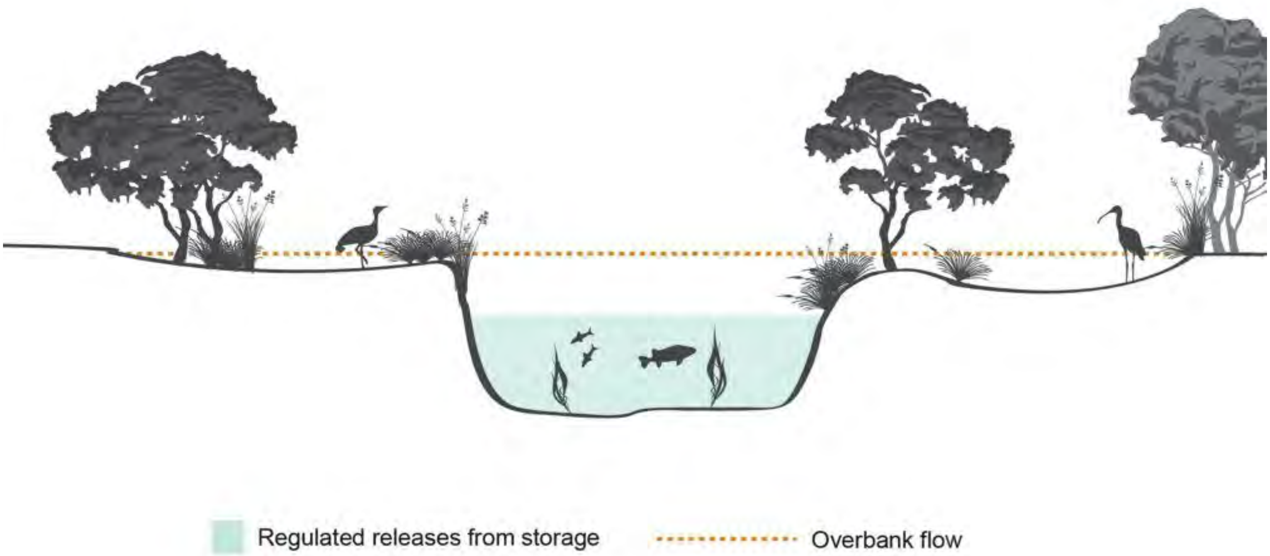


Figure 5: Regulated releases from storage are mostly restricted to in-channel flows

In the Murray–Darling Basin

The Murray–Darling Basin (the Basin) has become highly regulated. In 1891, the construction of Goulburn Weir near Nagambie, Victoria, marked the beginning of almost a century of construction of major assets to support irrigation in the Basin.

By the time Dartmouth Dam was completed in 1979, enough dams had been built across the Basin to store more than one year's average inflow. The large dams in the southern Basin — Burrinjuck, Blowering, Hume, Dartmouth and Eildon — were all sited at locations where they could capture and store as much inflow as possible.

These dams typically fill through winter and spring, and are subsequently drawn down through summer and autumn to support large-scale irrigation.

In the southern Basin, where 80% of the Basin irrigation occurs, the combination of dam construction and irrigation changed the rivers from winter–spring flowing to summer–autumn flowing and, in the process, eliminated most small flood events.

With Australia's highly variable rainfall and heavy irrigation use, it became quite common from winter–spring rain events to be almost fully captured in storages. Significant overbank flows only happen when the major storages have filled and, subsequently, spill. Thus, only the wettest 15% of years now result in significant overbank flows in the middle to lower Murray. Before development, such flows would have occurred in almost 50% of years.

The impact on floodplain species has been dramatic, with large areas of floodplain forests and woodlands dead or highly stressed.

Connecting rivers to their floodplains

Small to mid-sized flows, which are being considered by the Constraints Management Strategy (the Strategy), are vital to the environment. Before river regulation, these flows were common events and delivered a range of benefits (Figure 6).

Overbank flows:

- **improve water quality and supplies**, by
  - flushing salt from deep saline pools and sediments, including sulfidic material
  - flushing organic material from floodplain forests
  - reconnecting wetlands and billabongs to the river more frequently and for longer durations
- **improve soil quality and reduce erosion**, by
  - moving carbon and nutrients between rivers and floodplains
  - stabilising riverbanks by modifying river operating procedures and encouraging vegetation growth along waterways to reduce erosion and sediment supply
- **support native species**, by
  - stimulating native fish to feed, migrate and breed — for example, golden perch need high river flows to spawn, and floodplains make great nursery habitats to rear young fish
  - delivering water to wetlands that are located higher on the floodplain — for example, black box and ephemeral wetlands (occasionally wet and then have a drying period)
  - supporting habitat and breeding of water bugs and insects (an important part of the river food chain, as they are food for native fish)
  - allowing plants and animals to move throughout river systems and colonise new areas

- watering remnant patches of woodland along watercourses; these woodland patches are also often used to protect livestock and, if managed effectively, will continue to provide critical habitat for threatened species.

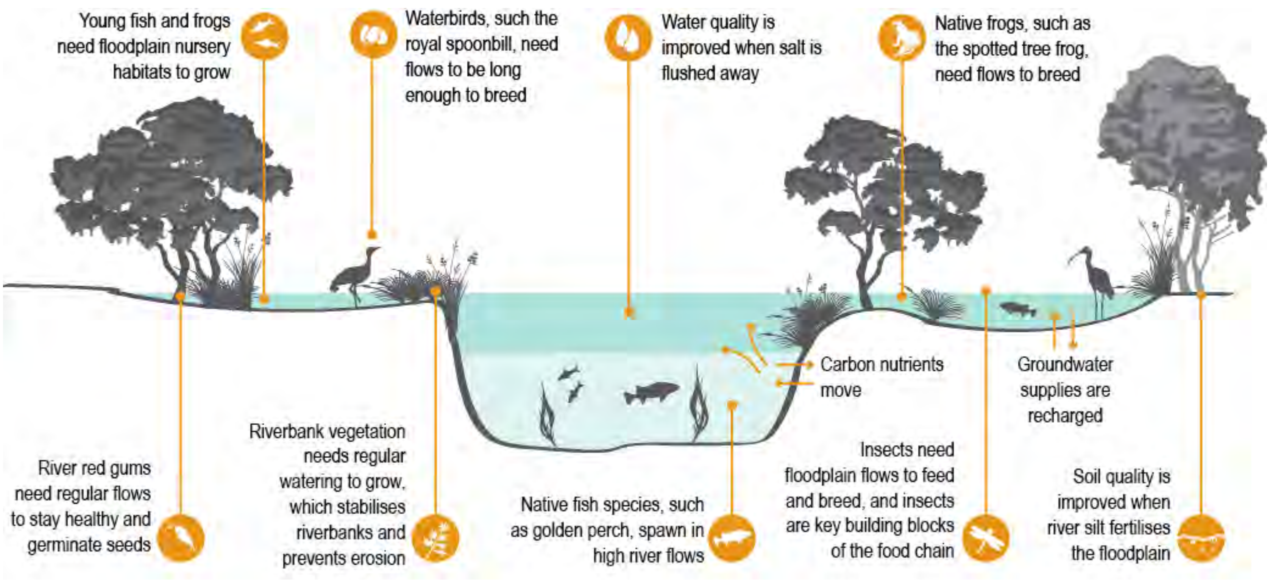


Figure 6: The environmental effects of overbank flows

Constraints to delivering small overbank flows are damaging the river environment. It is important to recognise that this threatens not only the natural environment, but the communities that depend on it. For example, good water and soil quality is vital to local farming communities along the river.

The proposed overbank flows will usually 'top-up' existing flows, increasing either their peak (river height) or duration (Figure 7).

Flows are important for many environmental processes, such as breeding and migration, and many species use weather conditions as triggers in anticipation of a large flow. Coordinating regulated water releases with rainfall events and catchment run-off makes use of natural ecological cues to improve environmental outcomes.

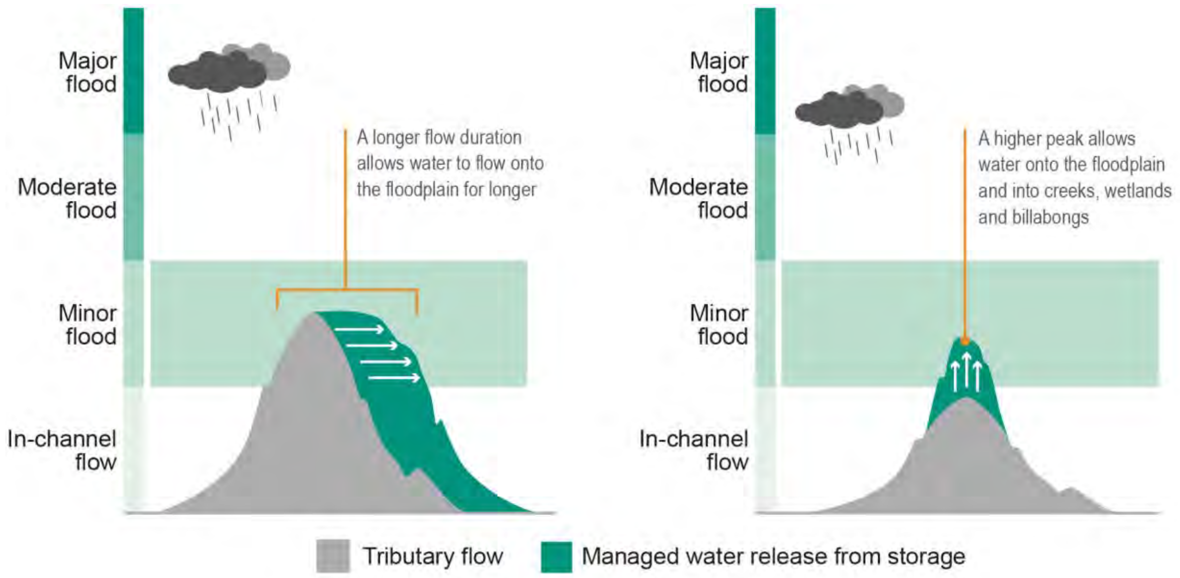


Figure 7: 'Topping-up' unregulated tributary flows with regulated releases to create small overbank flows

Why the Strategy is important in the Yarrawonga Weir to Wakool Junction reach

Over time, the River Murray, Goulburn and Edward–Wakool river systems have been modified and become highly managed. Dartmouth, Hume and Eildon dams store and deliver water for irrigation and consumption, which has significantly altered the timing and frequency of flow events as well as flow rates in these rivers.

Under natural conditions, river flows were highly variable, with high flows typically occurring in winter–spring and low flows in summer–autumn. Under regulated conditions, river flows are much less variable and now there are low flows in winter, and higher flows during late spring and into summer. These changes to seasonal flow patterns have disrupted the natural cycles of feeding, migration (or movement) and breeding (including flowering and seeding) for many plants and animals. Consequently, many native species associated with these waterways have significantly declined (Davies et al. 2008, 2012).

As well as changes in timing, flow rates and frequency of flows have reduced. As a result of these reductions, floodplains and riparian areas have been increasingly developed for agriculture. Parts of the floodplain that used to get regularly wet have now been developed for cropping, with additional infrastructure built (e.g. levees, weirs and block banks) to further regulate and divert remaining flows. Some of these structures have disconnected creeks, wetlands and flood runners from the river. This prevents the delivery of higher flows to support these areas without affecting these structures and private land.

> *In the Edward–Wakool system, combined regulated and unregulated flows are generally looking after the environment here. Our issue is with the ephemeral creeks, that's the downside of regulation and consumptive use. You need to think about smarter ways to get water to those.*
> Community member, Barham CMS meeting, June 2013.

Addressing constraints will improve the local environment by allowing water to access creeks, wetlands and billabongs in more natural patterns.

There are numerous environmental assets in this region — including native fish and birds, forests and wetlands — and there is strong community interest in improving their health. Landholders in various parts of the reach are putting time and effort into improving water delivery to these assets (see the case study below). Getting water to these assets is important both for their own health, but also the general wellbeing of the community.

Community helps to create a 'more natural' pattern of wetting and drying

A number of ephemeral creeks (have naturally wet and dry phases) that are located on private land are now being watered by individual landholders and through the use of large-scale irrigation infrastructure. One example is the Jimaringle, Cockrans and Gwynnes Creek system located west of Deniliquin in southern New South Wales. This creek network starts at the Colligen Creek and runs for more than 100 kilometres to the Niemur River.

Cockrans, Jimaringle and Gwynnes creeks are located higher on the floodplain and have been isolated from flows as a result of river regulation and floodplain development. Local landholders were concerned about the declining health of the creeks, dieback of trees, poor water quality and soil health. There were also concerns about salinity and acid sulfate soil. The community approached environmental water managers to see how these areas could get water.

Cockran and Jimaringle creeks used to be known as 'good fishing country' in the 1950s and 60s. However, in the 1970s, the system got too much water (partly influenced by the development of irrigation escapes) and this is likely to have caused the death of river red gums, black box and significant growth of cumbungi (Gordon Ellis cited in Green 2001).

Cockran and Jimaringle used to run once in every 5 years (sometimes once in 10), but in the 2000s, they received very little water. In the case of Gwynnes Creek, it had not had a drink for more than 40 years.

Landholders were hoping to 'bring the creek back to life' after wildlife experts discovered large numbers of animals and plants along the creek. Thirty-four landholders worked with the NSW Office of Environment and Heritage, Murray Irrigation Limited, the Commonwealth Environmental Water Office and Murray Local Land Services to undertake a watering trial in 2010. The success of the trial has led to three additional events in 2011–12 and more than 11,000ML of New South Wales and Commonwealth environmental water have been delivered.

Following the watering events, 9 species of frogs were recorded (there are only 14 across the region) with red gums, black box and common reed also responding. It was also great for water-dependent plants such as nardoo and water ribbon. Perhaps the most significant result was a record of the southern bell frog along Gwynnes Creek and the southern myotis bat (southern fishing bat) in Cockran Creek. There was also improvement in water quality, including a decline in salinity.

Source: Transcript: NSW OEH, Cockran, Jimaringle, Gwynnes E-water (OEH 2014a)

What is happening in the Yarrawonga Weir to Wakool Junction reach?

Catchment characteristics

From its origins south of Thredbo in the Great Dividing Range, the River Murray flows in a westerly direction for more than 2,500 km until it reaches the Great Southern Ocean. The major tributaries of the River Murray include the Mitta Mitta, Kiewa, Ovens, Goulburn, Campaspe and Loddon rivers that flow from Victoria, and the Tooma, Geehi, Murrumbidgee and Darling rivers and Billabong Creek flowing in from New South Wales. The River Murray also receives in-flows from the Snowy Mountains Hydro-electric Scheme at Khancoban.

This region is very flat, with gradients as low as 1:5,000. The landscape can be best described as a broad flat floodplain that is interconnected with a vast network of flood runners and associated creeks. Some areas in the western parts of the reach are slightly higher due to natural features such as sand hills and natural levees associated with larger rivers. Other parts of the system, which are slightly lower or that have a unique geography, have supported large expanses of floodplain forest. Historically, these forests would have received regular overland flows and would not have been suitable for agriculture. Land in these areas is often referred to as flood country.

Overall, the Yarrawonga Weir to Wakool Junction region is semi-arid with an average annual rainfall of just over 400 mm. The summers are hot and dry, and winters are cool. Vegetation is mostly made up of annual crops and introduced pasture (DECCW 2010), with less than 10% of pre-development native vegetation remaining.

Hydrology for the reach is complex with major contributing in-flows being delivered from two major river systems — the Murray and the Goulburn (Figure 8). The Edward–Wakool system then diverts and or receives water from both systems, and eventually passes these flows back into the River Murray downstream of Kyalite.

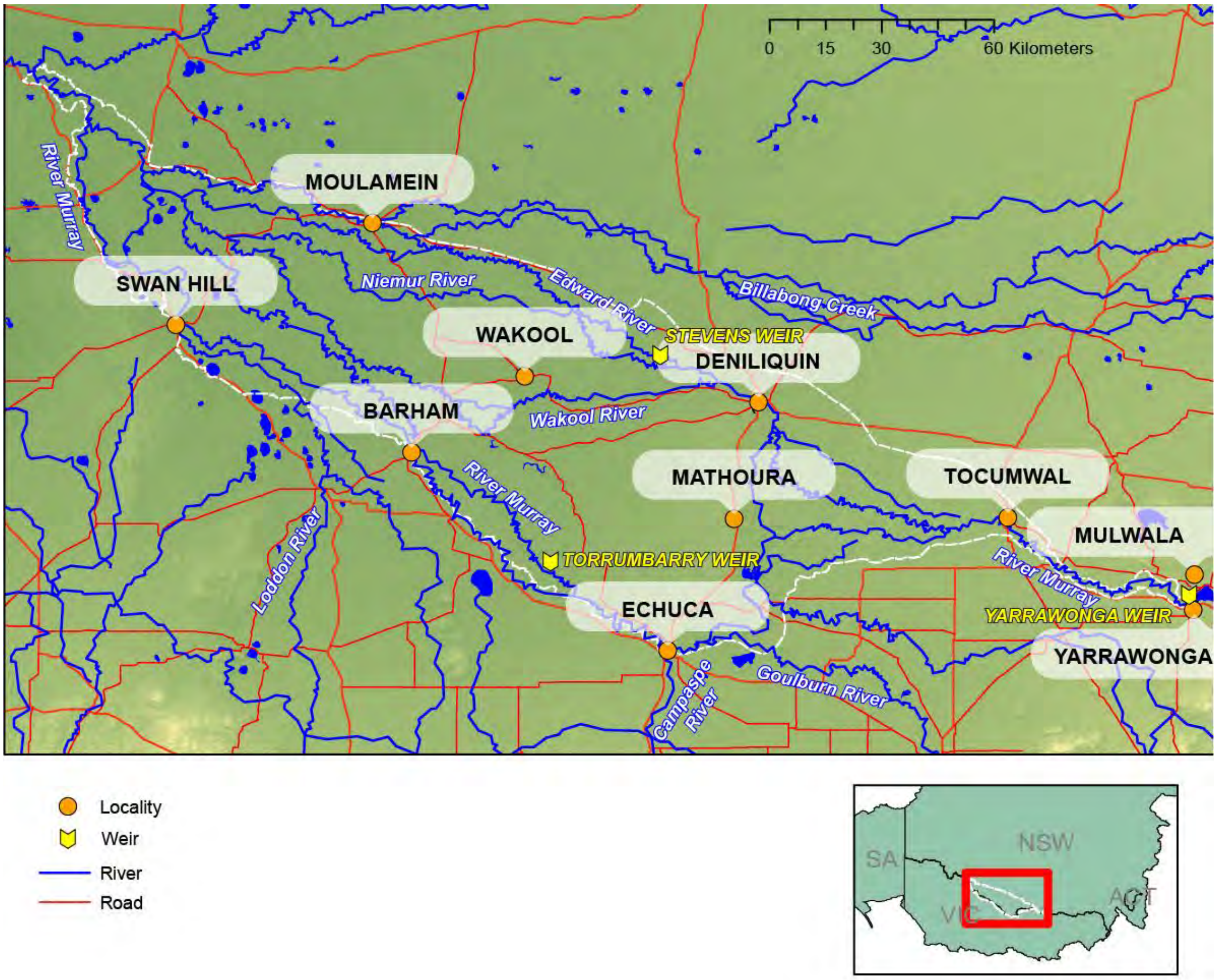


Figure 8: Map of Yarrawonga Weir to Wakool Junction reach

The River Murray is a large, low-gradient, anabranching river system characterised by low water and low flow energy. In this reach, the River Murray flows across a broad floodplain incorporating numerous anabranches, billabongs and wetlands (Thoms et al. 2000).

In this reach, the River Murray flows west from Yarrawonga through Tocumwal to near Mathoura where it reaches an area known as the Barmah Choke. The Choke is a part of the river that was formed as a result of a geological feature called the Cadel Tilt. The Cadel Tilt is an uplift that extends from near Deniliquin to Echuca and resulted in a change of course for the River Murray about 25,000 years ago. The current River Murray then follows the 'old' channel of the Goulburn River as it makes its way to Swan Hill.

River Murray flows between Echuca and Swan Hill are influenced by in-flows from major Victorian tributaries, including the Goulburn, Campaspe, Loddon and Avoca rivers. The river is generally a well-defined channel and an extensive levee network (both natural and constructed) that acts to keep the Murray within channel at small to mid-sized flows. At flow rates of more than 18,000 ML/day (Torrumbarry), water starts to enter the Koondrook–Perricoota Forest. At higher flow rates, however, water moves out of the River Murray channel between Echuca and Barham into the Koondrook–Perricoota Forest, and flows to the north and north-west delivering flows into the mid–lower Wakool River system via the Thule and Barbers creeks. Downstream of Barham, the Merran, Waddy Creek and Poon Boon systems flow north into the Wakool River. Flows then reach the lower part of the Wakool River, which is believed to be the former River Murray channel.

Merran Creek, a tributary of the Wakool River, April 2014. *Photo: Louise Ray, MDBA*.

The Edward–Wakool is a major anabranch system in New South Wales that leaves the River Murray in the Barmah Forest and re-enters the River Murray downstream of Swan Hill and Moulamein. The main offtakes from the River Murray are the Edward River and Gulpa Creek. At higher flows, the Tuppal and Bullatale creeks leave the Murray within the Millewa Forest and enter the Edward upstream of Deniliquin. The Wakool and Niemur river systems originate just downstream of Deniliquin with a number of associated watercourses, including the Yallakool, Colligen, Cockrans, Jimaringle, Gwynnes, Cunninyeuk, Mallan, Murrain Yarrein and Yarrein creeks. There are a myriad of flood runners that link these watercourses. Just upstream of Moulamein, the Billabong Creek enters from the Murrumbidgee catchment and contributes in-flows to the Edward River.

Floodplain behaviour

The Barmah Choke has a significant influence on higher River Murray flows. As River Murray flows at this part of the system increase, a larger portion of River Murray flows are directed north into the Edward River system. The Goulburn River, which enters the River Murray channel just upstream of Echuca, can also influence flow distribution, as high Goulburn River flows block River Murray flows with water consequently pushed to the north (Maunsell Australia 2009).

The volume of in-flows from contributing catchments means that a single, very high flow event with a short duration, from a single tributary may not result in high downstream flows. In contrast, a number of lower flow events, with a much longer duration from multiple rivers may fill flood runners and creeks, reducing their ability to 'take up' or reduce overland flows.

The area of land affected at a particular flow rate is significantly influenced by how wet or dry the floodplain is before the event. For example, a wet floodplain has less capacity to absorb water, therefore increasing the area of land affected when compared to an identical flow into a dry floodplain. The roughness of the channel also affects the behaviour of water. i.e. the amount of obstruction to flow – the Niemur and Edward rise at the same rate to a certain point until they begin to show different rates of rise – the Niemur River begins to rise at a faster rate than the Edward River as the Edward River flows must pass through the Werai Forest.

People and economy

More than 60,000 people live throughout the reach. Major population centres include Yarrawonga, Mulwala, Cobram, Barooga, Deniliquin, Echuca, Moama and Swan Hill. Land use across the region is dominated by agriculture, with more than 1,700,000 ha dedicated to dryland farming and more than 300,000 ha dedicated to irrigated agriculture. Approximately 150,000 ha of land within the reach is managed for conservation. This comprises almost 100,000 ha of public land such as National Park, conservation and reserve land.

Agriculture forms a major part of the region's economy, contributing $598 million, or 34% (2010–11), of the gross regional product (Murray Now 2014). In 2010–11, produce derived from irrigated agriculture (rice, dairy, grapes, citrus and cotton) made up 27% of the total agricultural production.

Recreational and tourism activities are increasingly providing economic diversification opportunities for local communities. Overall, the Murray region attracts more than 5 million tourists annually, who contribute significantly to local economies. For example, tourism in Echuca supports more than 1 million visitors who contribute more than $250 million annually (Murray Now 2014). The rivers and waterways host a number of key events, including the Mulwala and Wakool Fishing Classics, waterskiing and other water-based recreational activities.

Edward River at Deniliquin. ***Photo: Brayden Dykes, MDBA.***

Environment

A number of sites within the reach are recognised nationally and internationally for their environmental importance. The central Murray floodplain forests form a major component of the wetland assets in this reach. These floodplain forests represent the largest complex of tree-dominated wetlands in southern Australia and contain unique examples of floodplain lakes, meadows and reed swamps (NRC 2009).

Well-known environmental assets include The Living Murray sites (Barmah–Millewa and Gunbower–Koondrook–Perricoota floodplain forest network), and other national parks and wetlands are also listed as wetlands of significant international importance under the Ramsar Convention.[2] These reserves, which total approximately 124,000 ha, protect large sections of the river red gum floodplain forests that flank the River Murray on both the New South Wales and Victorian sides of the river.

The central Murray floodplain forests — including the Werai, Kyalite, Whymoul, Yallakool and Niemur forests — represent the largest complex of tree-dominated wetlands in southern Australia. In addition to these well-recognised areas, the reach contains a further 3,900 permanent and ephemeral wetlands (Green & Alexander 2006).

The rivers and their associated floodplain and wetland habitats support a diversity of habitats for a range of aquatic and terrestrial species. Large areas of flood-dependent vegetation communities occur throughout the reach. Flood-dependent vegetation communities are dominated by river red gum (*Eucalyptus camaldulensis*) and black box (*E. largiflorens*), and there are also areas of lignum (*Muehlenbeckia florulenta*). Many of the floodplain forests support complex networks of wetlands, some of which support locally and nationally significant wetland plants such as moira grass (*Pseudoraphis spinescens*), tall spike rush (*Eleocharis sphacelata)* and common nardoo (*Marsilea drummondii)*.

Native fish

This reach of the River Murray and the Edward–Wakool system, in particular, plays a critical role in supporting native fish within the Murray–Darling Basin. The waterways have historically boasted a high diversity of native fish species and is a major source for Murray cod (*Maccullochella peelii peelii*) along the Murray. However, studies have shown a general decline in native fish diversity and health across the region due to hydrologic and habitat changes (Davies et al. 2008, 2012). The Edward–Wakool aquatic ecosystem is recognised as an endangered ecological community in New South Wales (FSC 2002).

An iconic Australian native freshwater fish — the Murray cod — has a stronghold in the region (Lintermans 2007). This species is not only important from an ecosystem perspective, but is an important resource for the recreational fishery. Waterways in this region are important for this species because of the range and complexity of habitats they provide. There are also significant populations (albeit declining) of other threatened and vulnerable fish species including silver perch (*Bidyanus bidyanus*), and smaller fish such as rainbow fish (*Melanotaenia fluviatillis*) and southern pygmy perch (*Nannoperca australis*) (A. Conallin, Murray LLS, pers. comm, 30 July 2014).

Studies have shown that waterholes in the region provide a critical drought refuge for native fish species and, consequently, contribute significantly to the recovery of native species both at the local and Basin scale when flows improve (Gilligan et al. 2009). Slower backwaters such as

---

2 The Ramsar Convention (formally, the Convention on Wetlands of International Importance, especially as Waterfowl Habitat) is an international treaty for the conservation and sustainable use of wetlands, recognising their fundamental ecological functions and their economic, cultural, scientific, and recreational value. It is named after the city of Ramsar in Iran, where the Convention was signed in 1971.

billabongs and side channels in the region are also used as refuge sites for larval or juvenile fish species during high flow events (Koehn 1996).

Some fish species depend on higher flows that access the floodplain to meet all of their life history requirements. Golden perch (*Macquaria ambigua*), for example, are believed to rely on floods to enable breeding and floodplains make great nursery habitats for rearing young fish. Golden perch also migrate for long distances and rely on flowing rivers and creeks to enable this movement. Artificial wetlands and waterways, including farm dams, complement the natural systems wetlands through playing a valuable role in creating refuge areas for native fish species. This provides increased opportunity for fish to breed potentially protected from the threat of invasive species.

Work done in the region in the mid-2000s identified, assessed and prioritised a number of structures as key barriers for fish movement (DPI 2008). Since that time, a number of the larger water regulating structures have been re-designed or re-fitted with fishways to support the free movement of native species. A number of structures that prevent fish movement remain in the system (NSW DPI 2008).

NSW Department of Primary Industries studies (DPI 2007) have recommended that conservation and recovery actions for native fish within this reach should include allocating and managing environmental flows to emulate natural flows and improve instream vegetation, reducing the effects of unseasonal flow and temperature patterns, and providing fish passage by removing barriers or installing fishways (NSW DPI 2007). In particular, improved flow regimes for fish should consider the development of a variety of water habitats — fast flows, slow flows, overland flows and still water — to support the needs of different native fish species (Ye et al. 2014).

Birds

Wetlands and riverine vegetation in the region provide habitat for a range of colonial waterbirds such as the eastern great egret (*Ardea modesta*) and straw-necked ibis (*Threskiornis spinicollis*), as well as migratory species such as brolgas (*Grus rubicindus*) and Australasian bitterns (*Botaurus poiciloptilus*).

Bird species also benefit from the large corridors of remnant river red gum and black box woodlands that line many of the creeks and flood runners in the region. These mature forests contain large numbers of hollow-bearing trees that support hollow-nesting birds (and animals). Some of the numerous threatened and vulnerable bird species recorded in the area include diamond firetail (*Stagonopleura guttata*), superb parrot (*Polytelis swainsonii*) and bush stone-curlew (*Burhinus grallarius*). There is also considerable interaction between farm land and the natural environment. The creation of rice paddocks does create displacement, however in response to this, the paddocks then provide a valuable breeding refuge for the endangered Australasian Bittern (*Botaurus poicilotilus*).

Other species

The River Murray and its surrounding wetlands provides important habitat for many native frog species. Species recorded in the region include the southern bell frog (*Litoria raniformis*) (listed as ‘vulnerable’ nationally) and eastern banjo frog or pobblebonk (*Limnodynastes dumerili*) (Tyler 2009). As previously mentioned, there have been recent records of inland forest bat (*Vespadelus baverstocki*) and southern fishing bat (*Myotis adversus*) in Gwynnes Creek and Cockrans Creek.

Three species of turtles are found in the region, including the eastern long-necked turtle (*Chelodina longicollis*), Murray short-necked turtle (*Emydura macquarii*) and the broad-shelled turtle (*Chelodina expansa*) (listed as ‘vulnerable’ in Victoria). Variable flow rates are known to be required by the broad-shelled turtle, because it uses a variety of freshwater habitat types from connected backwaters, lakes and swamps through to the main river channel (MDBC 2001).

How the Yarrawonga Weir to Wakool Junction reach has changed

Since the early part of the 20th century, flows in the River Murray and its associated tributaries and anabranches have become increasingly regulated. Much of this change has been driven by the economic development of the region to provide a reliable and/or secure water supply for stock, domestic and agricultural use (Green 2001; DECCW 2010).

The River Murray is regulated by two major storages: Hume Dam and Dartmouth Dam. Hume Dam, located on the upper River Murray near Albury, was constructed in 1936 and enlarged in 1961, and has a storage capacity of 3,005 GL. Dartmouth Dam, constructed in 1979, is located on the Mitta Mitta River and has a storage capacity of 3,856 GL. Flows in the River Murray are highly regulated; Dartmouth and Hume dams both regulate 87% of the total inflow. The major tributary rivers (Murrumbidgee, Goulburn and Darling) for the River Murray are also highly regulated.

Regulated water delivery in the Edward–Wakool region is managed through a network of regulators, inlets, canals and syphons. The main regulating structures include the Gulpa Creek Offtake, Edward River Offtake, Edward River Escape and Stevens Weir. Regulated water can also enter the Edward River via the Mulwala Canal, which sources water upstream of Yarrawonga Weir delivering water through the Edward Escape into Stevens Weir. During irrigation season, the weir pool created at Stevens Weir raises water levels and enables water delivery into Colligen Creek to the Wakool Canal, Yallakool Creek and the Wakool River. The Mulwala Canal passes under the Edward River at Lawson's Syphon. Water can 'escape' into the Wakool River (at Wakool Escape) and to the River Murray at Torrumbarry (Perricoota Escape).

Changes in hydrology

Increased regulation has resulted in less variability of instream flows, reduced flood frequency, and a reduced area of extent and changes in duration of overland flows (Green 2001). Small and mid-sized flows that used to connect the rivers and creeks to the floodplain and its wetlands are now captured in dams.

As a result of dams, 'flood country' that was naturally inundated every year, or every two or three years, is now only being inundated every five or six years — or sometimes even longer. For example, at Tocumwal, there has been a 30% reduction of small flow events of 20,000 ML/d and a 50% reduction in their duration. Mid-sized flows have also changed; there has been a more than 40% reduction of flows of 50,000 ML/d and a 50% reduction in their duration. The story is similar at Deniliquin, with a 20% reduction in flows of 5,000 ML/d (just below 20,000 ML/d at Tocumwal) and a 50% reduction in their duration. Flows around 18,000 ML/d (just under 50,000 ML/d at Tocumwal) have also reduced in frequency by 50% and a 54% reduction in duration.

The reduced frequency of flows combined with the construction of levees, has meant that land that was predominantly unviable (due to excess flooding) could now be developed. Some of this land is used for grazing and other areas are opportunistically cropped. However, the reduction in flow also means that some land is not as productive as it once was. Some landholders on flood country are keen to have a few more small freshes or floods to 'wet the country up'.

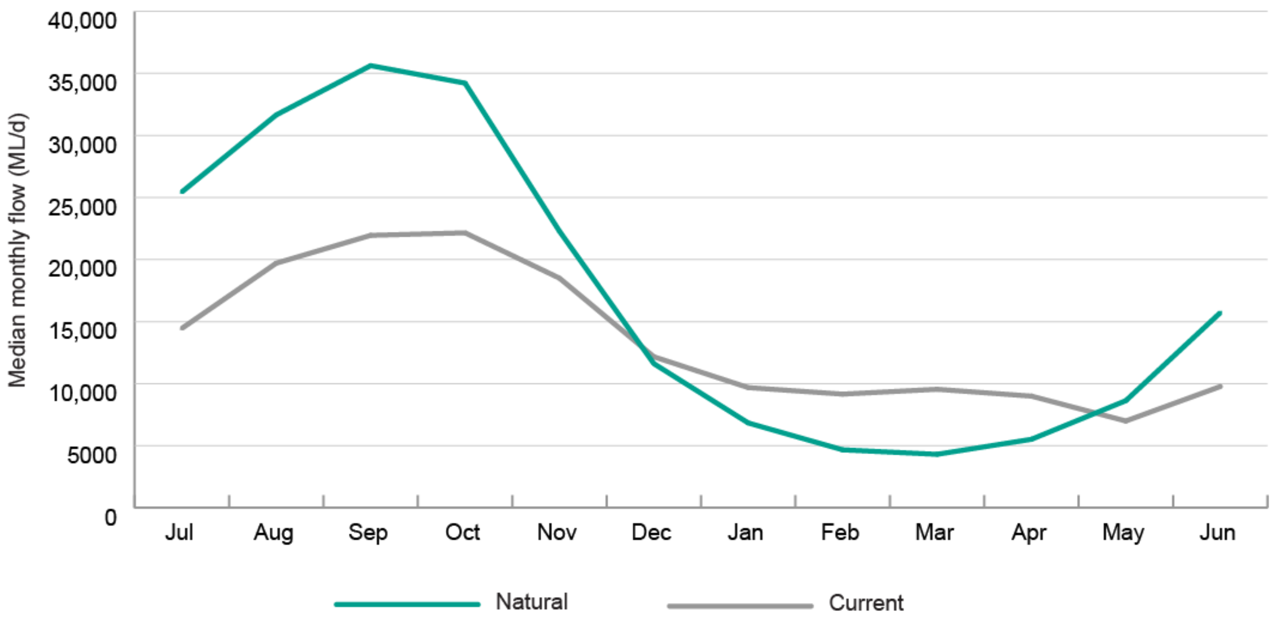
In the upper reaches (from Hume Dam to Yarrawonga Weir), flow has increased through the addition of water from the Snowy Mountains Hydro-electric Scheme. However, in the lower reaches (downstream of the major irrigation areas), the total volume of flow has been substantially reduced (Figures 9 and 10). In these areas, periods of prolonged low flow are now more frequent, whereas the frequency, duration and size of larger flows has decreased (Thoms 2000). In the lower reaches (downstream of Mildura), the river is operated as a series of weir pools.

Box Creek channel, April 2014. *Photo: Louise Ray, MDBA*.

Flood enhancement works have been built on the floodplain to improve delivery of water to the Gunbower-Koondrook-Pericoota forests. These works, built through The Living Murray (TLM) program, include regulators and levee banks which direct water into the forest, hold it there and then release it back to the River Murray via the Wakool River. This simulates a natural flood while using much less water. Under full operating capacity, the works will enable up to 16,000 ha of forest to be watered.

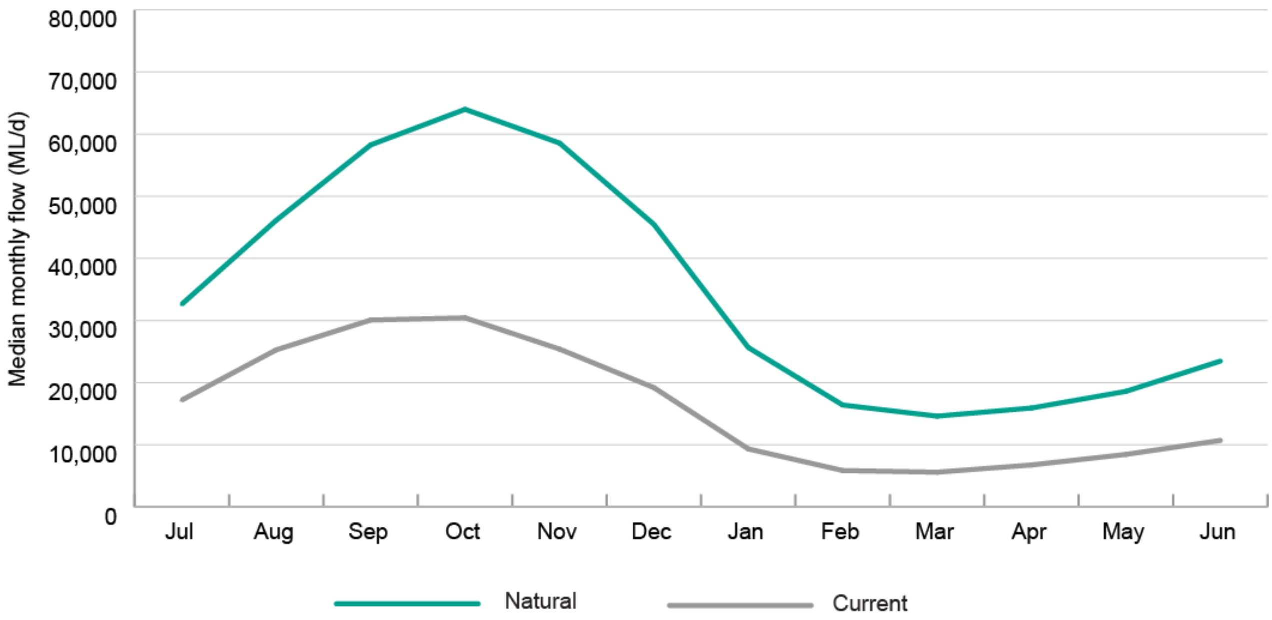
Floodplain development

There have also been changes on the ground. Floodplain development has seen the construction of numerous structures, including roads, levees, weirs and block banks, in an effort to divert and or retain water, as well as provide protection from flooding. These structures have affected how overland flows move throughout the landscape (DECCW 2011a), and have also influenced the health of aquatic ecosystems (GHD 2009). The combined effect of reduced flow frequency and floodplain structures has meant that wetlands that are away from the river channel, or located higher on the floodplain, are now stranded. Some of the animals that once used these areas are disappearing, and the plant communities are also changing.



Source: MDBA 2011

Figure 9: Comparison of the modelled natural and current median monthly flows downstream of Yarrawonga Weir



Source: MDBA 2011

Figure 10: Comparison of the modelled natural and current median monthly flows passing Lock 8

How the Yarrawonga Weir to Wakool Junction reach is managed

Flow in the Edward–Wakool system is managed cooperatively by the Murray–Darling Basin Authority (MDBA) and NSW State Water Corporation to meet the water requirements of local water users, as well as the wider water requirements of New South Wales, Victoria and South Australia. To do this, the agencies rely heavily on cooperation of Murray Irrigation Limited, who can transfer significant volumes of water from Lake Mulwala into the Edward–Wakool system via a network of irrigation channels and escapes.

During the ‘irrigation season’, water is often transferred through the Edward River system via Murray Irrigation Limited networks to deliver water to the lower Murray. This water bypasses the capacity restrictions of the Barmah Choke. When providing water to the lower Murray, a balance is maintained in both the River Murray and Edward–Wakool system where possible. During the irrigation season, water is also diverted from Stevens Weir on the Edward River into the Wakool canal to supply the Wakool Irrigation District. In winter, minimum flows are maintained along the Edward River to ensure adequate town water supplies, stock and domestic supply, as well as maintaining riparian and in-river aquatic ecosystems. In winter, the weir pool at Stevens Weir is generally lowered and in-flows to the Wakool River, Yallakool and Colligen creeks can cease.

Delivering water to meet the requirements of environmental water managers is relatively new. Patterns of environmental water delivery are likely to broadly follow seasonal cues — for example, rainfall patterns, which are typically higher in winter–spring. There may be other factors that influence demand, including meeting a specific need, such as to support a bird-breeding event or fish migration. There may also be a need to deliver a flow at a specific height to enable waterways and wetlands higher on the floodplain to get water. These water delivery patterns are likely to differ from the water requirements to meet crop demands, though there may be some overlap.

MDBA and State Water operators work cooperatively and liaise on a daily basis to balance the water requests. Complex computer simulation models are used to inform management of the river. Decisions draw on data from a number of sources, including:

- current river conditions
- channel capacity
- weather forecasts
- climatic conditions
- tributary inflows
- water travel time
- demands or orders
- order variability
- diverter behaviour
- gauge accuracy
- loss assumptions.

River operations are also guided by longer-term strategies and plans that consider the requirements and risks to the system during the coming months and years. This includes an annual operating plan that presents and analyses a range of scenarios that may be encountered in the upcoming season to inform preparation and planning. This plan is reviewed throughout the year and also informs a basis for operational planning in future years.

Current flow patterns

Operation of regulated river systems is based on the provision of flows within a range to support irrigation requirements and minimum flow provisions (regionally and downstream). Irrigation requirements generally follow crop demand patterns and do not vary significantly during the summer irrigation season from year to year.

The MDBA river operations team manages the day-to-day river operations of Hume Dam and water deliveries in the Yarrawonga Weir to Wakool Junction reach. Full-regulated flows within the upstream Hume to Yarrawonga reach are limited to 25,000 ML/day. During summer, regulated releases from Yarrawonga Weir are limited to 10,600 ML/day to minimise unseasonal Barmah–Millewa Forest flooding. Flows of more than 18,000 ML/day at Tocumwal are known to affect riparian landholders, because flows above this rate begin affecting low-level crossings, interrupting on-property access.

Although there is no long-term agreement for a maximum flow downstream of Yarrawonga, MDBA is aware of potential effects on landholders. The Basin Officials Committee has agreed for a temporary (2014–15) target flow rate downstream of Yarrawonga of up to 15,000 ML/day, with a potential increase to 18,000 ML/day subject to agreement by New South Wales and Victoria.

Environmental assets and constraints

During the past decade or so, there have been a number of water deliveries into the floodplain forests, wetlands, rivers and creeks within the region. Earlier large-scale water deliveries were focused on larger assets and broader ecosystem functions such as Barmah–Millewa and floodplain ecosystems. Smaller wetlands (2–400 ha), located on private land, have also been targeted with environmental water in this period in an effort to maintain and improve biodiversity values. Riparian landholders have been heavily involved in these events to ensure that third party effects are managed.

In 2013, a watering trial was undertaken to determine whether small flows (18,000 ML/day at Tocumwal) could be effective in supporting the health of moira grass plains of the Barmah–Millewa Forest (a critical wetland vegetation community as defined in the Ecological Character Description of these Ramsar sites).

The 2013 Barmah–Millewa trial was a relatively small event — 18,000 ML/day (Tocumwal). Flows of up to 18,000 ML/day did not provide the required extent, depth and duration of flooding. Consequently, not all of the forest received water, which means that river red gums will continue to encroach into the moira grass plains. Flows were also too low to allow moira grass germination (DPI 2014).

Improved flexibility in flow delivery patterns would give forest managers a greater ability to manage forest health and provide the river–floodplain connection that is essential for native species and carbon–nutrient exchange. It would also reduce the risk of hypoxic blackwater events[3] by delivering flushing flows more frequently through the forests and dilution flows within the major waterways.

Flow rates of at least 35,000 ML/day would enable forest managers and environmental water managers to deliver water to approximately 55% of the floodplain's forested area. It would also enable more effective management of the site, as well as improve water quality and instream benefits for the creek and river systems (NRC 2009).

Since 2011, the New South Wales and Australian governments delivered almost 100 GL of water as part of the Edward–Wakool Fish Flows project (OEH 2014b). This study aimed to develop management strategies to deliver water in a 'pulse' to encourage movement, spawning, and recruitment of large- and small-bodied native fish (Watts et al. 2012). Interim results from long-term monitoring is showing that small-bodied native fish increased in numbers, water quality was maintained and there were no changes to numbers of large-bodied native fish. Regulated flows are limited to 600 ML/day in the mid-Wakool River, which enables cod nests to remain underwater. However, increased flow rates (for short durations) would provide benefits for both native fish and the river.

Floodplain planning and management

Much of the Yarrawonga Weir to Wakool Reach is located on a floodplain. Floods since the settlement of the region, and the continued growth of agricultural development, has seen wide-scale development of flood protection measures — mostly levees — to protect agricultural land (Maunsell Australia 2009). Considerable farm income losses following major floods has resulted in periods of 'flood protection' construction in the mid-1950s and the early 1970s. Overall, these broad-scale construction activities resulted in an uncoordinated and complex flood management system and, in some cases, provided little protection during subsequent flood events (SMEC 2003).

Levees are the principal flood protection tool and were typically built to protect housing, sheds, grain storage, crops and livestock. Levees were generally designed to confine flows to particular watercourses or to flood runners (SMEC 2003). These alterations to the floodplain may change how future floods are expressed (DLWC 2000; SMEC 2003).

[3] When organic material, such as leaf litter, decays in wetlands and waterways, it darkens the water — known as 'blackwater'. Blackwater and the decaying process is a natural and important nutrient cycling process. However, when organic material decays, it uses oxygen held in the water. Under the right conditions (warm water and high volume of organic material), too much oxygen can be taken from the water, causing a hypoxic blackwater event that can stress or kill aquatic species.

A levee bank, which protects agricultural land along the northern boundary of the Barmah Forest. ***Photo: Jody Swirepik.***

Floodplain planning

Floodplain planning typically constrains development in flood-prone areas in an effort to reduce the risk of damaging floods. In New South Wales, designated floodways are designed to pass flood water easily, and provide a balance between social and economic benefits as well as environmental benefit by supporting flood-dependent ecosystems. In Victoria, planning controls limit modifications to the floodplain that impede or alter flows. A number of structures that could potentially impede increased regulated flows remain within floodways in the region.

The principal method for controlling development within the NSW parts of the floodplain is through the development of floodplain management plans. These statutory documents aim to:

- provide floodways with adequate capability to allow for effective and efficient discharge of floodwaters
- enable flood protection for agricultural land and other property
- maintain and restore natural patterns of flooding to support floodplain environments, in particular, flood-dependent ecosystems
- ensure floodplain management is consistent with relevant New South Wales state planning instruments and natural resource management policies
- determine where landholder flood protection works can and cannot be constructed.

The New South Wales section of the Edward–Wakool reach is covered by five separate floodplain management plans (DLWC 2000, DECCW 2011 a, b, c, DNR 2004). These plans include the identification of designated floodways, which are designed to allow the passage of flood waters while attempting to balance social, economic and environmental outcomes. Unapproved works or structures in these areas that impede or divert flows are therefore prohibited. Detailed mapping has been undertaken in this reach to identify potential impediments to the free flow of floodwater through the floodway network (Maunsell Australia 2009). The study found a number of approved and unapproved structures within the designated floodway network.

In Victoria, catchment management authorities (CMAs) manage floodplain planning for this reach, they are the Goulburn-Broken CMA, the North Central CMA and the Mallee CMA. Floodway planning overlays are the main tool used to direct CMAs on development assessment decisions in flood-prone areas.

The identification of a floodway network is not typically based on the largest, or possible, maximum flood. For example, some of the floodway networks in the west of the Edward–Wakool are designed around events with a 15–20 year average return interval, which is more like the 1975 floods, as opposed to the larger, 1956 event (Maunsell Australia 2009).

It is also important to note that floodway networks are generally not specifically designed to provide any particular level of protection. For example, in New South Wales, the installation of levees is generally a private landholder decision and is voluntary, with the levee construction funded privately. Further, the selection of a particular height for a levee and/or its design is also generally a landholder's decision, except where flood management plans specifically limit the height — for example, the Tulla levee along the Wakool River (Maunsell Australia 2009).

If the Yarrawonga–Wakool reach was to proceed to feasibility assessment, the affect these structures would have on increased regulated flows would need to be better understood.

At flows of 35,000 ML/day, flows through the Barmah Forest appeared to be dependent on the levee network along the northern and north-eastern boundaries of the forest. This levee protects agricultural land. The River Murray Floodplain Inundation Model (RiM-FIM) showed that, at flows of 50,000 ML/day, agricultural land in parts of the Niemur River system may be reliant on the rural levee network to protect crops from flooding. At flows approaching 77,000 ML/day, more areas throughout the reach will potentially be reliant on the rural levee network as well.

Groundwater

Large-scale effects of saline groundwater expressing throughout the western part of the reach in the 1960s and 1970s led to the development of the Wakool Tullakool Sub Surface Drainage Scheme (SMEC 2003). Salinity issues are believed to have declined since this period as a result of the development of the scheme, as well as the construction of flood control measures and the establishment of the floodway network (SMEC 2003). Analysts believe that a floodway network with adequate capacity should limit groundwater recharge by moving flows quickly off the floodplain, particularly for large flood events. Reconnection of some of the wetlands located higher on the floodplain may potentially increase groundwater recharge both through inundation of land and through the bank profiles of water ways. The combined effect of flood control works and the infrequency of wetting is believed to have minimal effect on recharge (SMEC 2003).

Rural floodplain levees

The levee network throughout the region is extensive but is non-contiguous through some areas. Current standards of construction, maintenance and regulatory status of many of the rural flood plain levees is poorly known in the New South Wales parts of the reach. Information on levee condition is reasonably well known for rural levees in Victorian parts of the reach. Further detailed work is needed to understand the levee network and its ability to contain increased regulated flows within this reach.

There are generally two main types of levee systems: urban or township flood protection levees, and rural floodplain levees. The former are designed to protect housing and community infrastructure where townships are located in areas prone to flooding. Rural levees, on the other hand, are mostly designed to protect farming land and assets from the effects of flooding. Homes in rural areas are typically located higher on the floodplain and are not generally at risk except for extremely high flow events; however, there was at least one residence located within the New South Wales floodway networks (Maunsell Australia 2009). The residence is protected by a ring levee and was not shown to be affected by the flows being examined by the Strategy. The MDBA made numerous requests for data on levee networks to the NSW Office of Water; however, the data were not supplied.

Construction of levees date back to the late 1800s and early 1900s. However, levee construction is generally episodic and typically commences or follows major flood events — for example, in 1956, 1974 and 1993 (Maunsell Australia 2009). Levee maintenance has become an important factor in ensuring the functionality of both rural and township levees to provide the expected protection. The New South Wales Government is currently finalising a state-wide program to understand the design objectives and current condition of township levees in key towns in the state. The Victorian Government has recently supported rural and township levee condition assessment studies for the Goulburn–Broken and North Central catchments.

Levee bank within the reach showing erosion on the levee toe associated with tree growth. *Photo: Terry Korodaj, MDBA*.

Mapping flows and understanding potential effects

A number of hydrologic studies have been conducted on components of the waterways within this reach. In addition, a small number of studies have examined the potential effects of increased flows within the reach (MCMA 2012a, 2012b). No single study, however, has been undertaken to understand the broad-scale hydrology and the interactions between waterways and the major upstream catchments. An integrated study is needed of the hydrology and inundation to discover what flows might be feasible and what mitigation measures might be needed.

In developing the Constraints Management Strategy (the Strategy), the MDBA used several tools to examine and develop an understanding of river processes and their effects. One of these tools included hydraulic modelling, which was used to generate indicative inundation extents or 'flow footprints' of various flow scenarios. These outputs helped identify indicative areas of land that are likely to get wet for different flow rates. More specifically, it enabled the MDBA to determine what native vegetation and wetlands would be potentially inundated on the floodplain, as well as agricultural land use, roads, bridges and other infrastructure that may be affected.

The hydraulic model approximates how water moves down the river and across the landscape. Models use a combination of digital elevation data, including bathymetric data where available, and satellite images of historical flow events. The models are then able to provide a prediction of flow at a gauge downstream. It is important to note that the relationship between a flow event and predicted inundation extent is not stable and can vary depending on conditions and geomorphology. Physical changes to the river and floodplain, both naturally and through regulation and development can alter flow behaviour and flooding extent. Further, models cannot account for all conditions that may occur before or after a flow event (i.e. antecedent conditions), which may alter the inundation extent.

The flow footprints for the Edward–Wakool reach were created using the RiM-FIM. This flood inundation model was developed by CSIRO as a Water for a Healthy County Flagship project.

Inundation or flood maps for the Yarrawonga Weir to Wakool Junction reach

In the Yarrawonga Weir to Wakool Junction reach, RiM-FIM collected information from a range of historic events that occurred during the past few decades. The results reflect changes in river regulation and floodplain development during this time. Data for daily river flow heights were collected after 1974, and satellite images were used for events dating back to 1988. Data were processed and analysed, and inundation maps or flood footprints were produced for the entire reach at each of the flow rates being studied — 20,000, 35,000, 50,000 and 77,000 ML/day, based on flows at the Tocumwal gauge[4].

---

[4] CMS prefeasibility work in the Yarrawonga-Wakool drew on information which was generated with reference to both the Tocumwal and downstream of Yarrawonga Weir gauges. Inundation maps (i.e. the areas modelled as inundated at specified flow rates, which informed the assessment of effects and/or impacts of higher flows) were generated with reference to the Tocumwal gauge, while hydrological data (i.e. frequency, timing and duration of flows) were generated with reference to downstream of Yarrawonga Weir. Flow rates at the two sites are similar, but not identical—in general, a given flow rate downstream of Yarrawonga Weir equates to a slightly lower flow rate at Tocumwal. For practical purposes the discrepancy is not material to the information described in this report, in fact, the discrepancy results in more overestimate mapping.

Adjustments to RiM-FIM modelling and some considerations

Antecedent condition (i.e. whether the catchment is wet or dry before a flood event) can have a large influence on predicting where water goes (see 'Floodplain behaviour'). Attempts were made to capture this where possible by using historic flow events that followed a rainfall event in the previous six months. This was done to simulate the largest extent likely at a particular flow rate. Despite the design of this approach, there were some limitations. For example, a 'good' satellite picture of an event is needed which shows the peak flow and the image also needs to be free of cloud cover.

In some cases, it was not possible to capture the peak of an event because of cloud cover or the timing of the imagery. In this situation, an alternate image at a similar flow rate was used. In some cases, these events did not follow a large event. Of the 33 events selected to build the model, all but 3 events were chosen after a 'wet event' and most were collected during the generally wetter periods between 1989 and 2001, and in 2010–11. The three events that were chosen during dry years were for the Niemur River at the Barham/Moulamein Road gauge, however the flows selected reflected stable regulated flows for that location, resulting in a smaller inundation extent this particular location. To compensate for the 'drier' catchment, increased flow rates were used to reflect the likely conditions at that gauge under a 'wetter' scenario.

Validating flow footprints

After the maps were produced by CSIRO, hard copies of the maps were sent to the Edward–Wakool Constraints Advisory Group and a series of 12 meetings to review the maps were held in early 2014 with local experts, community members (mostly adjacent river landholders) and local councils. These meetings included presentations of the flow footprint maps, explanation of the method and limitations for developing the maps. Attendees were asked to review flow rates and the extent of flooding at each flow rate. In summary, feedback from across all reviewers included:

- Community members in some areas and agency staff felt the flow rates for most areas seemed representative, except for the lower part of the Niemur River where the flow rates seemed too high, yet the corresponding flow footprints did not reflect a correspondingly large area of inundation. This information on the Niemur River was reviewed and taken into account in estimating mitigation costs. In contrast, some community members felt that each of the maps underestimated the footprint of the flows at all the flow rates selected.
- Most community members felt that the flow footprints at the highest rate (77,000 ML/day at Tocumwal) underestimated the area flooded, because they knew that flooding occurred in some parts of the region at flows of 30,000 ML/day (Tocumwal).
- Local council engineers and flood planners for the towns of Tocumwal, Deniliquin, Moama and Barham felt the flow footprints were quite accurate at all the flow rates being studied for quite specific locations where historic flow levels and flood footprints are well known and receive detailed scrutiny.
- There were a few instances where some landholders felt the inundation footprint was exaggerated; for example, near Taylors Creek between the Tuppal and Bullatale creeks. Here, areas were shown as inundated at the highest flow rate (77,000 ML/day) and some believed these areas were not likely to be connected at this flow rate.
- The RiM-FIM model did not appear to accurately reflect changes in flow height for deeper river channels. For example, water against the town levee at Tocumwal was not readily detected by the model at any of the flow rates, despite local knowledge of known river effects at specific flow rates. Water depth was not available in this rendition of RiM-FIM,

however, additional processing of the existing data may enable depth values to be calculated more accurately.

Following discussions with councils, local hydrologic experts and community, there did not appear to be a strong ‘lived experience’ of the types of flows being examined, particularly at the lower flow rates. However, recollections were very strong for recent major flow events, including 2000 and 2010 where flows exceeded 90,000 ML/d at Tocumwal, and 1996 with flows around 140,000 ML/d at Tocumwal.

Evidence of this can be seen with the current maintenance challenges associated with low-lying bridges in the west of the region. A number of these bridges were built in the 1900s, before the major storages were constructed. These structures allowed people to move through the landscape during periods when the creeks and flood runners were flowing. As river regulation continued, less water passed and the need for these structures became less important. During this time, farm machinery increased in size and weight. Bridges built to previous design standards now no longer support the vehicles moving over them and a lack of water resulted in the adjacent creekbed being used to provide passage.

Disused timber bridge on Nacurrie Road in the Wakool Shire. ***Photo: Phil Townsend, MDBA.***

How MDBA used the flow footprint maps

The MDBA used the flow footprint maps to perform a desktop analysis to determine how flows would affect agricultural land, townships (including roads, bridges and other structures), public land, large-scale irrigation infrastructure, native vegetation and wetlands across the reach .

Data for these analyses were sourced from publicly available datasets, or data sourced under licence. Data for major infrastructure and cadastral information were assumed to be of high standard and the data quality was taken as supplied. Data on minor crossings had significant accuracy limitations and these data had to be reviewed by visual assessment of aerial photos and satellite imagery. Land classification data also had accuracy and resolution limitations, particularly as land-use classifications are often assigned on a whole-of-cadastre basis even though different portions of that land may be used for different purposes. These limitations were taken into account by consultants in estimating mitigation costs to the level of accuracy needed for prefeasibility.

Additional detail on the flood inundation mapping and desktop analyses is contained in a companion technical report. Inundation maps that were produced for the pre-feasibility assessment for this reach will be available for download from MDBA's website—www.mdba.gov.au.

Mitigation strategies

Only a small number of mitigation strategies were selected for costing on the basis that these strategies:

- were practical and represented likely future strategies
- could be readily costed with some level of accuracy
- could have the costing method applied consistently across all key focus areas.

There are likely to be other significant cost factors that would need to be assessed if the reach was to move to feasibility assessment. Some of these may include relocation or access to water pumps, relocation of existing low-level crossings and relocation of existing on-farm track networks.

Prefeasibility cost estimates for this reach considered major and minor infrastructure, including roads, bridges and low-level crossings, as well as easements across land. Flood protection levees may become a potentially important mitigation strategy for parts of this reach and would have been an important factor for inclusion in costing. Data on the floodplain levee network, as previously stated, was not made available for this assessment.

Full details of the assumptions underpinning the cost estimates — including hydrological assumptions, economic assumptions, assumed infrastructure works required and construction standards — are contained in separate companion technical reports. It should be noted that construction standards for bridges and low-level crossings were based on current Australian standards for these structures. Further, width of crossings assumed the need to pass large-sized agricultural and heavy machinery. Estimates of easement costs were broadly based on market value for land, as well as current land use and costs of management.

Actual mitigation cost estimates for this reach are in the Constraints Management Strategy annual report 2014.

What flows are being considered for the Yarrawonga Weir to Wakool Junction reach?

We are looking at possible new ways to manage the River Murray and waterways within this reach to ensure their long-term health, while avoiding or minimising the effects on people who also depend on the river. The environmental objective for this reach is to allow the rivers and creeks to connect with its floodplain more often than currently happens, but not as frequently as pre-European settlement.

In 2014 we investigated a range of small to mid-sized overbank flows (20,000, 35,000, 50,000 and 77,000 ML/d) at Tocumwal. The Constraints Management Strategy (the Strategy) is investigating adding an extra two to four flows every decade in the flow range of between 20,000 and 35,000 ML/d at Tocumwal. At flows of between 50,000 and 77,000 ML/d, we looked at an additional one to two flows per decade. The timing of these managed flows would be between June and November when the floodplain needs water most.

For additional information on the downstream flow rates and associated river gauge heights for the flows being examined for Yarrawonga Weir to Wakool Junction, see Appendix 1. Further work is being done on locating and incorporating local gauges that communities use to assess river height.

How these flows were chosen

Increased flexibility in the ability to release environmental water would result in improved local and regional outcomes for native fish, waterbirds and wetlands. It would also contribute flows to ensure 'all-of-system' outcomes, including the River Murray downstream of this region, into Mildura and the Lower Murray floodplains.

The highest flow rate of 77,000 ML/d was originally selected as it represented the 'minor flood level' at Tocumwal. It also represented the higher end of flows under consideration for this section of the River Murray. However, ministers decided in late 2014 that 65,000 ML/day would be the new upper limit for future investigations.

The four flow rates examined in 2013-14 were based on specific flow rates at Tocumwal and then calibrated for downstream gauges to generate flood maps. These maps were then used to determine potential effects of flows on both the environment and the community. See also 'Mapping flows and understanding effects'.

The four flow rates examined in the Yarrawonga Weir to Wakool Junction reach were:

- 20,000 ML/d (at Tocumwal) — which represents flows that were just above the current regulated flow constraint
- 35,000 ML/d (at Tocumwal) — which represents flows that would readily reach targets for the Barmah–Millewa Forest and upper reaches of the region
- 50,000 ML/d (at Tocumwal) — which represents flows that would begin reaching a number of disconnected wetlands and ephemeral creeks in slightly higher parts of the landscape and along the system for its entire length. Disconnected wetlands and creeks which may benefit from these flows include—Tuppal, Cockrans, Jimaringle and Gwynnes creeks.
- 77,000 ML/d (at Tocumwal) — which represents flows at which many of the disconnected wetlands in the higher parts of the floodplain could receive water. For example, over 75% of Barmah-Millewa Forest receives water at this flow rate.

When and how often these flows would happen

The timing for small to mid-sized flows would be winter and spring (June to November), not the summer irrigation season. This matches the time of year when rain and unregulated tributary flows typically occur throughout the region and in upstream catchments. It is also when floodplain plants and animals need the water most.

Flows of this size already occur in the reach; however, they don't occur as often they used to. For example based on the long term average of 107 years of flow rate data:

- flows at 20,000 ML/day (Tocumwal) currently occur on average about 3 times a year; in pre-regulation conditions, flows at this rate used to occur on average 4 times a year
- flows of 35,000 ML/day (Tocumwal) used to be reasonably frequent (3 times a year), but now occur about once a year; the frequency of this flow rate might increase slightly from current to occurring on average once every 9 months
- flows of 50,000 ML/day (Tocumwal) used to occur 14 times in 10 years on average, but now occur 8 times in 10 years; the frequency for this flow rate might increase to 2 additional events per decade
- flows of 77,000 ML/day (Tocumwal) used to occur 6 times in 10 years, but now occurs only 3 times in 10 years; the frequency for this flow rate might increase to one additional event per decade.

It should be noted that the long-term average frequencies described above are for events of any duration.

Different watering patterns can achieve different outcomes. Low flow rates can be used for long durations (e.g. months) if the objective is to provide base flows in rivers, and to 'fill-up' or maintain low-lying wetlands and billabongs, and to deliver for end-of-system objectives. Mid-range flow rates of medium duration (e.g. weeks) could be used in addition, to support in-river processes such as facilitating fish breeding, chances of survival, migration and access to food through connecting floodplain habitat. Very high flow rates could be used for short durations (e.g. days) to fill wetlands higher on the Edward-Wakool floodplain or to contribute to downstream environmental outcomes.

What is not being considered

We are not trying to create or change how often moderate and major floods occur (such as those that occurred in 1974, 1981, 1993 or 2010). These are recognised as being damaging and disruptive to communities, and are outside the bounds of active river management. Large-scale floods will continue occur with or without the Strategy.

An important consideration in developing a likely flow scenario will be contributions from unregulated tributaries during a regulated release. High in-channel flows may prevent tributaries from draining freely and cause back-up effects. For example, the Goulburn River is known to block River Murray flows at higher flow rates, pushing water north into the Edward River system. Similar processes may also occur with River Murray tributaries downstream of Echuca, as well as the Billabong Creek flowing into the Edward River at Moulamein. Further work will be conducted in 2015-16 to determine the scope and likely significance of this issue for communities at the junction of tributaries, particularly to better understanding the likely duration of regulated water releases from Hume and Eildon dams, and contributions from unregulated systems.

Options for changing managed river flows in the Yarrawonga Weir to Wakool Junction reach

It is difficult to predict when higher flows may occur, as they will be highly dependent on the weather and seasonal characteristics. However, it is possible to discuss potential scenarios that could be examined in future work. The following sections describe three artificial scenarios that help to frame how flow events might be built within this reach. All flow rates described are at Tocumwal.

Small flow events — 10,000–20,000 ML/day

In terms of smaller flow rates, it is probable that flows could be expected to be delivered in most years. Durations would likely be lengthy (weeks to months) to support fish or bird breeding activity, or to fill wetlands. Water could also be delivered in very dry periods to support drought refuges. Timing is likely to broadly follow a winter–spring pattern.

Flow events of this size could be wholly made up of ‘regulated water’. This type of scenario, however, is unlikely as environmental water managers would be looking to deliver environmental water efficiently. Adding regulated water to unregulated ‘natural’ events would help achieve this aim. If *only* regulated water was to be used, this could be delivered either by using water held by environmental water holders or by adding onto deliveries of consumptive water.

Small to mid-sized events — 20,000–50,000 ML/day

Small to mid-sized flows (20,000–35,000 ML/day) could be expected every few years. These flows would meet very specific objectives, such as periodic watering of the Barmah–Millewa Forest. At these flow rates, duration may be shorter than at lower flow rates; however, the timing is more likely to follow a winter–spring pattern. It is likely that there would be existing inflows from Ovens and Kiewa rivers, and releases from upper storages.

Flows of 35,000–50,000 ML/day would be less frequent on average than events at lower flow rates. Objectives for these types of flow rates are likely to be quite specific. Timing of these types of events would likely be strongly linked to flow events from the Ovens and Kiewa rivers. Such flows are not likely to occur if catchments are dry or during drought.

Mid-sized events — 77,000 ML/day

Flows at this rate could occur less frequently than for lower flow rates. The timing of these types of events are likely to be associated with unregulated inflows from multiple catchments. For example, to achieve this flow rate at Tocumwal, it is likely that the Kiewa and Ovens rivers would be flowing well and additional water would be released from Hume Dam. Additional downstream contributions may be required from a combination of regulated and unregulated releases from the Goulburn River and other Victorian rivers.

What might be the effect of the proposed flows in the Yarrawonga Weir to Wakool Junction reach?

At a glance

An assessment of wetlands and floodplain-dependent native vegetation likely to be accessed by the flow rates studied shows a significant increase in benefit at all flow rates. These flows would also help to flush salt from deep saline pools and the floodplain, and move organic matter from floodplain forests.

Some landholdings in the western parts of the reach may benefit from some form of periodic flooding to support grazing and opportunistic cropping.

The main effects at lower flow rates include impeded access, crop and livestock management issues, flooding or isolation of river pumps, and damage to fencing. At higher flow rates, areas of flood country will become flooded and access impeded. Some low-lying bridges and property access roads will potentially be cut-off. Some agricultural operations that are currently reliant on low-level crossings may be disrupted at each of the flow rates that were assessed.

Environmental effects

Reconnecting the floodplain with rivers, wetlands and creeks has a range of benefits for native fish and the river and wetland systems that support them. Increased flows will also support the recovery, growth and reproduction of vegetation communities.

Table 1 shows a basic analysis of the area (in hectares) of wetland and floodplain vegetation that are estimated to be inundated by the flows being studied. The area inundated was calculated using the River Murray Floodplain Inundation Model (RiM-FIM) inundation footprints prepared for this reach, as discussed previously. Analyses were prepared using inundation footprints compared with vegetation (Cunningham et al. 2013 and the National Vegetation Information System — NVIS 4.1) and wetland (Australian National Aquatic Ecosystem wetlands database) data for the Basin. The results are indicative at this stage; however, increased flows show considerable increase in benefit for target wetlands and native vegetation. Details of these analyses are available in the companion *Priority constraints analysis* report.

Table 1: Area of wetlands and flood-dependent native vegetation that would be inundated at the flow rates being studied for the Yarrawonga Weir to Wakool Junction reach

Flow rate (Tocumwal ML/day)	Red gum woodland ('000 ha)	Red gum forests ('000 ha)	Black box ('000 ha)	Shrub lands ('000 ha)	Wetlands ('000 ha)
20,000	14	13	6	<1	18
35,000	33	26	13	1	23
50,000	46	32	18	2	25
65,000	62	38	30	4	28
77,000	70	41	43	6	30

Different flow thresholds have different effects on native vegetation and wetlands, depending on the location of the wetland or vegetation in the landscape. Figure 11 shows that the increase in area of wetlands begins to level out between flows of 50,000 and 77,000 ML/d. In contrast, areas of inundated red gum woodland continues to increase beyond 77,000 ML/d, and areas of inundated black box woodlands increases rapidly beyond flows of 50,000 ML/d.

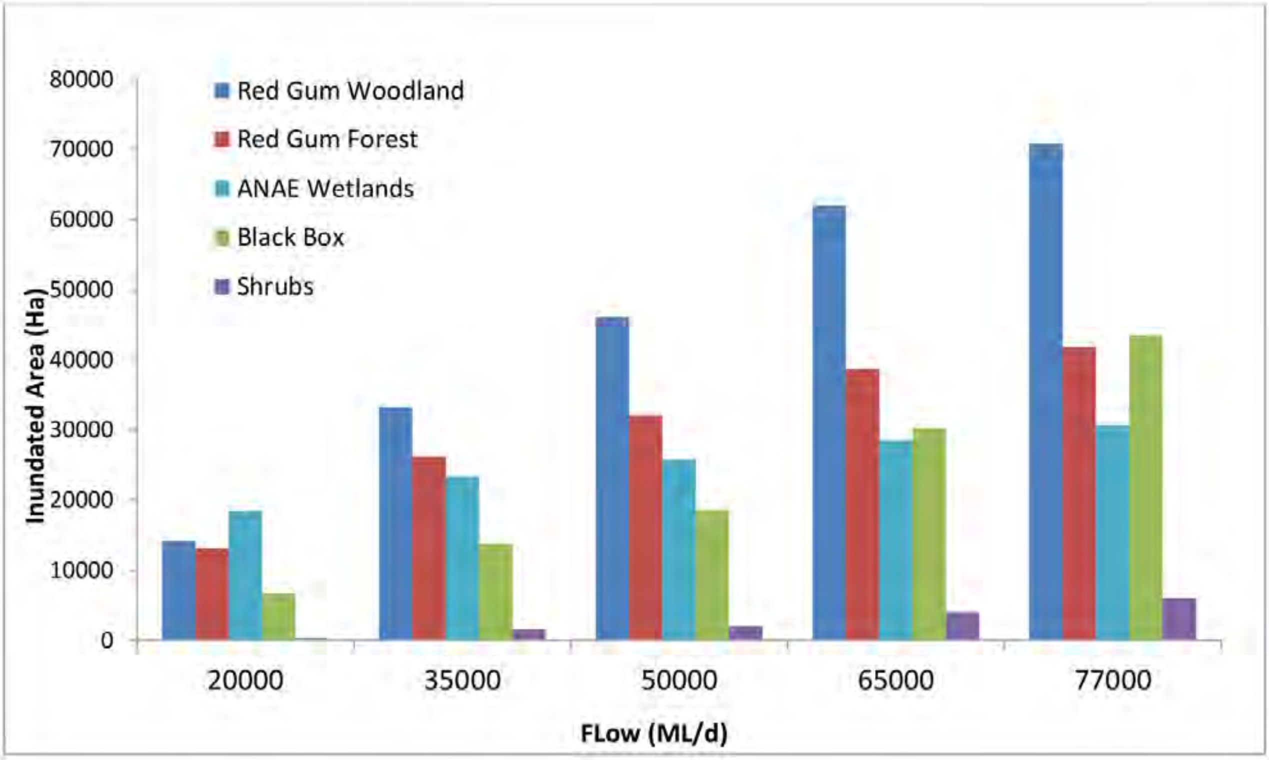


Figure 11: A comparison of the area (ha) of wetlands and flood-dependent native vegetation that would be inundated at the flow rates being studied for the Yarrawonga Weir to Wakool Junction reach

The NSW Office of Environment and Heritage has been opportunistically documenting and assessing the values of the many private wetlands contained within the reach. Murray Irrigation Limited has also conducted work to assess the values of wetlands contained within its irrigation districts. Some of this work has identified that wetlands 'higher' in the landscape are disconnected as a result of floodplain development. Further work would also need to be done to explore the degree to which disconnected wetlands can be reconnected by increased flows.

Third party effects

A series of desktop analyses of potential effects and mitigation costing was undertaken to provide an indicative prefeasibility assessment for the costs of enabling increased flows. Data and information analysts at the Murray–Darling Basin Authority (MDBA) used desktop assessments to estimate the effects on land and public infrastructure. This assessment used intersections between modelled flow inundation areas, and geographic information system–based spatial data on land use and infrastructure assets. Independent consultants calculated the estimated costs associated with mitigating the effects on land and infrastructure. Additional information on the methods used can be found in a companion technical report and in reports by the consultants (GHD and URS). This section highlights only those effects identified through the desktop analyses. Local landholders provided considerable feedback on potential effects, and these have been detailed in the section ‘What does the community think?’.

Flood mapping produced for the analysis was intentionally conservative — in other words, the flood maps were designed to show the greatest extent likely (or a ‘wet’ catchment) at the flow rate being considered. This was done to ensure prefeasibility costing was as conservative as possible, considering the data and time available (but also understanding that costing will be further refined in future phases). As such, these data and results (including community perception of actual effects) should be seen as indicative only and designed to provide a broad-scale assessment of effects to enable decision making for prefeasibility comparison between key focus areas.

The frequency, timing and duration of higher flows will alter the impacts created by these flows. Future flow patterns will depend on, and be determined by, future environmental watering decisions. Additional hydrologic modelling work is required to describe the likely future flow patterns. This information would also help potentially affected communities to describe the likely effects of higher flows.

Interrupted access

Higher environmental flows could result in interrupted access, which occurs when land is not itself inundated, but when access to it is cut-off through inundation of adjacent land and/or access routes. This potential interrupted access is of concern to agricultural enterprises.

From a farming perspective, many of the enterprises that are adjacent to the rivers and creeks in this region are typically divided by a local creek or flood runner. Because there is productive land on either side of the waterway, landholders have built low-level crossings within creek beds and the beds of flood runners to access different parts of their properties. The current flow regime (and the rules for harvesting water in major dams) means that these low-level crossings can be used almost year round with little risk of getting wet. When unregulated flows occur, these crossings are easily drowned out and landholders already manage for these events.

Low-lying farm crossing along the Wakool River in the western part of the reach. ***Photo: Jody Swirepik, MDBA*****.**

For those enterprises that rely on access across a creek or flood runner, interrupted access may mean a disruption of a business activity in which there is a considerable investment. For example, if access is required to maintain a crop or livestock, the investment (time, money and opportunity cost) may be high, and the management activities may be time and/or weather critical. Reliability of access increases the certainty of being able to respond to crop management and livestock needs.

If these low-level crossings were upgraded to allow for increased regulated flows, landholders would also enjoy the improved access provided during unregulated flow events. Further, if permanent structures were built, the costs and effort required to repair crossings after any flow event would likely be reduced.

Low-lying farm crossing on Bullatale Creek in the eastern part of the reach. Note the wide channel of the creek. *Photo: Terry Korodaj, MDBA*.

A risk currently exists for these enterprises in terms of unregulated events. For example, an upstream rainfall event may deliver enough river flow to overtop these crossings. In these cases, landholders accept the residual risk that remains following construction of the major upstream dams and are willing to accept the current risk of the crossing being ‘drowned out’. Landholders, however, are generally unwilling to accept the risk of a ‘managed’ or regulated event interrupting access, as there is a belief that if the event can be controlled, there is an obligation to avoid a third party effect.

Many of the low-level crossings that have been built on agricultural land throughout this reach do not appear to have been designed to survive flooding without damage. As such, the structures typically require repairs or a major rebuild after each significant flow event. Construction materials of existing crossings typically comprise timber, clay and/or gravel, combined with rock (where possible) and/or building materials such as bricks and concrete. Some of the larger structures allow a relatively limited passage of water, often through concrete pipes. It is possible these structures may prove impassable for native fish. This is partly because native fish tend to avoid moving through poorly lit structures, but also because the head loss (height between the creek and upstream flow) may be too great (DPI 2008). Replacement of these structures would need to ensure that fish passage is facilitated and that these structures do not impede the free flow of naturally occurring floods.

Repair works on a low-lying creek crossing following damage associated from an earlier natural flow event.
Photo: Terry Korodaj, MDBA**.**

Other property assets that are potentially affected include water pumps located adjacent to waterways. In the situations where a pump is below the proposed water level, it would be 'drowned' and become damaged. In other cases, where river pumps are isolated during higher flows, the pump can still operate but the access track to the pump may be inaccessible. In this case, the pump wouldn't be damaged, but a lack of access could prevent the timely watering of irrigated crops, leading to lost production.

In addition, there are likely to also be a number of associated management costs, which may include fencing and pest management. Indirect costs could include animal welfare issues and post-event clean-up activities (e.g. removal of debris against fences, pasture siltation).

Inundation or flooding

At higher flow rates, inundation or flooding of low-lying land increases and is greatest at the highest flow rate being examined. The duration of an event will likely significantly influence the level of impact. That is, pastures and crops may be able to cope with relatively short periods of inundation but are likely to die during periods of extended inundation. Extended duration may also limit the ability of landholders to access flooded land.

The timing and frequency of inundation events will also affect how much impact there is on pastures and crops. This is discussed further in subsequent sections of this report. Increased overland flooding would also potentially increase the impacts of interrupted access, as described in the previous section.

Each farming enterprise across the reach is different and two neighbouring landholders with apparently similar operations may have different enterprise strategies and therefore be affected in different ways. A detailed property-by-property assessment is required, focused on discussions with individual landholders.

Flooding of crops may have significant impacts, even for short durations (two to three days). Although cropping activity accounts for only a small proportion of areas potentially affected, even at the highest flow rate examined, it is a generally a high value investment for the landholder. Flooding of pasture may have a lesser effect, but this would be dependent on pasture type and duration of the event. Improved pasture is likely to have a much shorter tolerance for inundation, whereas native pasture may be able to tolerate longer periods of inundation. It should be noted that plant death due to inundation is partially driven by inundation of roots, rather than the above-ground parts of the plant. This means that soil saturation, rather than plant inundation per se, may have a greater effect on crop survival when inundated.

Some landholdings in ‘flood country’ take advantage of flood events to graze or crop opportunistically. Some landholders expressed an interest in a slight increase in the frequency of floods to ‘wet the country up’, provided that the time between events was not too frequent and duration of inundation was kept relatively short.

A crown reserve network operates on the Victorian side of the River Murray. Parks Victoria and the Victorian Department of Environment and Primary Industries manage grazing licences throughout this network. Grazing licences can be obtained for periods of 1 or 5 years, and there are approximately 200 active licences currently operating between Wodonga and the South Australian border. Discussions with Victorian landholders and agency staff suggest that at flows of more than 30,000 ML/day at Yarrawonga, creeks and anabranches start to fill and interrupt access. At flows of above 60,000 ML/day at Yarrawonga, many areas along the Victorian side of the River Murray would become inundated. Additional work is required to understand the effects on these areas.

Table 2 provides a summary of the desktop analyses results. Data in Table 2 shows the additional effect at each flow rate, with the incremental effect detailed in brackets. Data from these results were used to estimate mitigation costs for the prefeasibility assessment of this reach. Details of costing methodology and assumptions are contained in a separate technical report and consultants reports (GHD and URS).

Table 2: Summary of potential effects at each of the flow rates being studied for the Yarrawonga Weir to Wakool Junction reach. Values represent the total effect at each flow rate (additional effect at each flow rate is provided in brackets for comparative purposes).

Effect	Up to 20,000 ML/day	20,000–35,000 ML/day	35,000–50,000 ML/day	50,000–77,000 ML/day
Sealed road (km)	2.8	3.1 (0.3)	3.9 (0.8)	6.7 (2.8)
Unsealed road (km)	4.1	12.3 (8.2)	25 (12.7)	62.8 (37.8)
Culverts (no.)	67	132 (65)	177 (45)	212 (35)
Bridges (no.)	28	37 (9)	39 (2)	41 (4)
Agricultural land (ha)	11,400	20,000 (8,600)	27,600 (7,600)	67,300 (39,700)
Ratio of public:private land inundated (%)	45:55	47:53	58:42	49:51
Area contained within floodway (%)	91*	91*	91*	87
Flood-dependent native vegetation (ha)	34,300	74,600 (40,300)	98,700 (24,100)	162,000 (63,300)
Wetlands (ha)	24,000	37,800 (13,800)	43,600 (5,800)	51,600 (8,000)

* The assessment method used to map inundation footprints recorded all sources of surface water, including farm dams and rainwater. The 9% of area outside of the floodway network can be attributed to these additional sources of water.

Changes in timing and duration of flows

Potential issues relating to a change in timing of regulated flow deliveries could potentially include a disruption to farming activities and changes in competition for channel share.

An increase in regulated flow deliveries from the current late spring–summer pattern towards a winter–spring pattern may affect agricultural activities where landholders are dependent on low-level crossings, or where land is flooded (see above). Mixed farming enterprises which rely on access to remnant woodlands or forests may be affected through an inability to manage livestock, for example, remnant vegetation may be used to house winter off-shears and lambing ewes to provide protection from poor weather. Adequate forewarning of events, may be able to provide opportunity to relocate stock or provide feed, however, a local rainfall event (unpredicted) which extends the event may continue to limit access to livestock potentially resulting in more complex management issues.

Competition for channel share

Environmental water delivery is likely to ease channel competition, particularly during summer–autumn, as the majority of the environmental water demand will likely occur in winter–spring. However, in this reach, there may be channel competition at times when delivering environmental water and South Australian entitlement flow if there is insufficient volume in Lake Victoria and Menindee Lakes. In this case, transfers of water from Hume Dam to Lake Victoria would be required to ensure delivery of the South Australian entitlement.

The last time supply was restricted was in 2003. The restriction was agreed to by the New South Wales, Victoria, South Australia and Australian governments within the provisions of the Murray–Darling Basin Agreement (MDBA can only act in accordance with arrangements agreed to by the signatories of this agreement). Historically, interim arrangements have been agreed to when channel competition is likely to occur. This is more likely to be because of a delivery shortfall rather than demand exceeding maximum channel capacity. MDBA river operations continually manage water deliveries within the current channel capacity to minimise the likelihood of competition occurring.

Irrigators are currently benefiting from the ‘good neighbour’ policy practised by, for example, the Commonwealth Environmental Water Holder, in which orders for environmental water are voluntarily given lower priority to channel access in situations where environmental water objectives can still be met.

MDBA will undertake further analysis of channel capacity competition as the long-term behaviour of environmental water holders and any emerging issues become clear.

Increased frequency of flows

Increased frequency of some flows may be problematic for agricultural land within flood country, particularly where current enterprise strategies have been built around reduced flow frequencies following the construction of major dams. Increased flow frequency of overland flows or floods may be problematic if the additional frequency causes an increase in interruption to operations, and those interruptions result in direct losses or opportunity costs. A more significant effect impact would occur if increased flow frequency forced a change in land-use practices. The prefeasibility study did not specifically assess changes in land use associated with changes in flow frequencies.

What does the community think?

At a glance

The Edward–Wakool Constraints Advisory Group, landholders from across the reach, local councils, government agencies and Murray Irrigation Limited have contributed their knowledge and opinions to this report.

Concerns remain for small and mid-sized flow rates, as there are a number of third party effects at all flows being studied. A recent watering trial showed that third party effects occur at flows of less than 20,000 ML/day at Tocumwal. There was a broad recognition that the effects of smaller flows could potentially be manageable, and that these flows could have environmental and community benefits. Some landholders were keen to see an increase in flows to improve river and waterway health, provided that risks could be managed.

Overall, in regards to all the flow rates studied there was strong concern about an increased risk of creating or exacerbating large or unmanaged floods, either in the same season, or in a subsequent year. The community rejected the suggested 77,000 ML/day (at Tocumwal) flow. There were also considerable concerns relating to flood risk at flows of 40,000 ML/day and 50,000 ML/day (at Tocumwal). Any changes will rely on governments being able to mitigate impacts on third parties.

As requested by the community, improved understanding of the potential for increased flood risk, and a demonstration that these risks can be effectively managed, is a key component in any future work. This work is critical in helping build community confidence in identifying acceptable future flow rates.

This section of the report reflects information collected after talking with community members throughout 2013–14, and was subsequently revised following a period of community feedback in early 2015 on the draft report published in December 2014. A series of meetings were held with a representative group of potentially affected landholders, local government councils, regional and state government agencies, and private corporations. The Murray–Darling Basin Authority (MDBA) also held local targeted meetings with landholders to seek specific views about different river/creek systems and about the Constraints Management Strategy (the Strategy) in general.

MDBA developed broad-scale assessments of flow or flood footprints, as well as desktop assessments of potential effects, which aided discussions with each of the major stakeholder groups**.** Landholders indicated that these maps did not necessarily reflect the extent of inundation they had experienced historically from the flows they were based on. Landholders also felt the maps had not adequately accounted for contributing flows from other sources, including Broken, Goulburn, Loddon, Avoca and Campaspe rivers from the south, as well as the Billabong Creek from the Murrumbidgee River to the north.

The major focus for the stakeholders meetings was broadly similar and was targeted at understanding the flow rates being examined for the Yarrawonga Weir to Wakool reach. The main themes included:

- When and how is private and public land, and infrastructure affected by the different flow rates?
- What are the potential effects at each of the flow rates?
- How well do the flow footprint maps represent the flow rates?
- What flow rates are considered unacceptable and why?

Indicative flow footprint or flood inundation maps were developed to help understand where flows might go at the specific flow rates being studied. The maps were designed to provide a 'back of the envelope' estimate that would be suitable for the broad landscape-scale assessment being undertaken during this prefeasibility assessment.

The following sections of this chapter directly report on the feedback that was provided by each of the stakeholder groups — landholder and land managers, local government, regional and state government agencies, and corporations.

Landholders

In 2013, the MDBA formed a group that has since become known as the Edward–Wakool Constraints Advisory Group. The MDBA met with this group on a number of occasions between 2013 and 2014, and discussed a range of issues associated with increasing regulated flows through the region. The membership of this group comprised mostly private rural landholders from across the geographic breadth of the region. The group also included people responsible for managing the major public land assets in the region, a major irrigation company, as well as representatives from forestry and the national parks estates.

> *We are happy to work with you [to deliver] environmental flows, but the risk needs to be kept low.*
> Community member, Bullatale Creek CMS meeting, June 2013.

During 2013 and 2014, the MDBA held 16 community meetings in this reach, the majority with potentially affected landholders. More than 200 individual community members were involved, contributing more than 1000 hours of personal time, including meeting attendance and associated travel. Advisory group members spent additional time reviewing written materials. An additional 11 meetings were held with local New South Wales councils, and further meetings were held with private corporations, and with New South Wales and Victorian government agencies.

Potential effects of increased regulated flows

On the whole, landholders recognise that they live on a floodplain and that damaging floods occur as a result of unregulated events. Landholders accept this risk as part of living and working in this environment. In contrast, landholders don't want to accept the risk of a river operator or other decision maker delivering water (or on top of a regulated event), which increases the current risk of a damaging flood above the historic frequency.

The following information summarises concerns and observations raised by community members (mostly private landholders) during the meetings. Comments have been grouped into the following topics and **do not** represent order of priority:

- increased risk of uncontrolled flood events
- clarifying who carries liability for third party impacts
- competition for channel share — productive water
- interrupted or impeded access to land — isolating stock and prevent crop management
- overland flooding — significantly altering current land activity
- floodplain management planning — may limit activities in floodways
- frequency, timing, duration and predictability of proposed flows — critical to understanding effects
- managing access during emergencies — bushfires

- potential for environmental damage — increases in pest species, riverbank erosion, tree loss and siltation/sedimentation
- groundwater recharge — increased salinity risk
- devaluation of private land asset
- public and private infrastructure — effects on bridges, buildings and pumps
- tourism — frustrated river access, uncertainty in holiday planning, increased exposure to mosquitoes and sandflies
- adequacy of funding — dividing community, transparency and clarity of processes
- environmental watering
- levee bank maintenance
- it is not physically feasible to deliver the environmental flows targets used to inform the Basin Plan
- changes in water demand patterns (through the Basin Plan) alter river flows, which affect how private diverters can access water
- potential public health impacts — effects from increased exposure to mosquito-borne diseases.

Increased risk of uncontrolled flood events

A main area of concern regarding the delivery of higher flows centres on the potential for environmental delivery events to exacerbate flood risk. Catchment condition (upper catchment soil moisture, recent flow history and wet/dry conditions of Barmah–Millewa and Koondrook Perricoota forests) and historic flood variability, combine to make flow behaviour difficult to predict through the reach. Local knowledge of previous flood events shows that flows of 40,000–50,000 ML/day increase flood risk, although in some parts of the system, flows of 20,000–30,000 ML/day would start to increase flood risk parameters.

The community have asked for an independent study into the issue of environmental flow delivery potentially exacerbating flood risk. This issue will be further investigated through 2015-16.

Catchment condition

A ‘wet’ catchment will likely result in a much larger flood footprint than if the catchment is dry for a given rainfall event. This may well result in greater variation of land being inundated in the central and western parts of the reach. Modelling for the reach should assume ‘wet’ catchment to ensure credibility with landholders. Another key influence is whether the rivers, creeks, billabongs and forests are already wetted up from recent flows.

Tributary inflows from additional sources both above and below Tocumwal must be considered. These sources include, but are not limited to, the Ovens, Goulburn, Broken, Loddon and Campaspe systems from the south, as well as the Billabong Creek from the Murrumbidgee system to the north.

The community wanted an improved understanding about who would wear the risk and liability for ‘managed environmental flows’ events that are above historic regulated releases that cause third party impacts.

Flood variability

Every flood event is different and the water expresses itself differently in terms of flow height and flood footprint. However, there is good local historical knowledge of flood risk parameters, which includes events in the Murray, Goulburn, Edward, Wakool, Campaspe and Avoca river systems. Behaviour of flows and the area inundated can be very different between events, even if the flow rate is the same. Multiple rainfall events in catchments can 'stack' water on top of earlier events increasing the risk of subsequent flooding. Merging of flows in different river systems can also back water up in the River Murray. This is particularly the case around the Barmah Choke, where the Cadell Tilt influences River Murray flows. For example, when a flooded Goulburn River (Victoria) merges with flows in the Murray, flows are diverted north into the Edward River system or west along the Murray channel. As water is backed up, this increases local flood heights in surrounding areas.

Further, because of the flat landscape, a series of drainage channels have been constructed throughout the region to work in concert with effluent streams to drain water from the landscape and return it to the river systems. This drainage system allows off-river land, inundated by a large rainfall event, to drain quickly so as not to cause excessive delays to farming systems. The concern is that if river levels are high, the drainage channels and/or effluent streams will not be able to flow into them and, therefore, land disconnected from the rivers may be left vulnerable to either backflow or rainfall inundation.

Conduct trials of small events

Undertaking trials of smaller events can help to understand the effects of flows on third parties and so demonstrate that risks can be managed. Trialling flows would help to build trust with landholders, while also providing government agencies with the opportunity to better understand how water flows through the region. Flow trials of environmental water deliveries have already been done in parts of the region. Future trials could see flow rates gradually increased and be supported by monitoring to ensure the effects were well understood. Future trials at higher flow rates should only take place after the negative impacts are effectively negotiated with third parties.

Red gum regrowth

Red gum sucker regrowth clogs waterways and creates flood water barriers (e.g. proliferation of suckers can block debris, creating 'beaver dams' and diverting flows). There is currently a 'blanket ban' on removing red gum suckers in waterways. Governments need to be practical on the need to develop policies that allow greater flexibility to manage red gum and other native species regrowth within designated floodways and in specific riparian zones, if required.

Maintaining channel integrity

Fallen timber within the river channels are diverting flows. Current New South Wales laws prohibit removing trees from waterways, as they provide potential habitat for species such as Murray cod, and realigning them to be parallel to the bank it is a very costly and time-consuming exercise that landholders do not do. An adaptive and flexible approach to managing riparian areas to maintain channel integrity is critical to ensure the effective and efficient delivery of environmental flows through tributaries and effluent streams into the main River Murray and downstream to Coorong Lower Lakes in the future.

The community felt that the MDBA and the Commonwealth Environmental Water Holder would need to support the maintenance of channels in certain high-priority areas to maintain the integrity of the waterway for the efficient transmission/delivery of environmental water. Landholders cannot be expected to do this.

Competition for channel share

Competition between productive and environmental water will be an issue if demands are called at the same time. Understanding the timing of flows for the environment is critical to knowing if there will be competition.

The delivery of high environmental flow targets can potentially compromise irrigation water supply. Of particular concern is flow share capacity and potential for restrictions being placed on irrigation water orders to ensure that historical regulated capacity is not exceeded. Current environmental watering practices in New South Wales have recognised the river channel capacity and potential third party impacts.

Water access for river pumpers

Recently, the MDBA has publicly stated they intend to run river operations differently (i.e. running rivers for environmental flows and productive flows). This may have implications for the deliverability of irrigation orders in some circumstances. Several different scenarios can arise and operational changes to the Murray River will have flow rate implications for other smaller rivers and creek systems. Higher river levels may mean landholders with river or creek pumps may have to lift their pumps. Conversely, if the Murray levels drop below current operational levels, then irrigation water orders may not be deliverable compared to current arrangements. This will have dramatic impacts on farm business planning in relation to cropping and stock management activities.

It was stated at each of the community Basin Plan consultation meetings that there was not allowed to be any third party impact on the deliverability or reliability of water for consumptive use. In setting environmental flow targets, these issues will need to be considered.

Interrupted or impeded access to land and water

Impeded on-farm access may result in isolation of stock, which could affect timely animal husbandry, as well as prevent or delay crop-management activities. Isolation may be problematic if the duration of the event is greater than available food supplies, or farmers are prevented from undertaking other stock management activities. Forewarning of an event may not be adequate for all landholders to allow stock to be moved or for additional food to be supplied, although other factors may need to be considered (i.e. lambing ewes, calving cows). This is because each business is different and their needs are not uniform.

Changes to historic flow regimes may mean that landholders with irrigation and/or stock and domestic supply pumps may not be able to access water if they have to lift their pumps during these higher flows. The extent of this issue depends on the frequency, timing and duration of the proposed flows.

Isolated crops may prevent management activities that are time sensitive — for example, sowing, pest and weed management, and harvesting. Forewarning of an event may be suitable in some cases; however, crucial management windows may be missed if the duration of an event is extended. Some impacts may not be able to be mitigated and would need to be ‘worked through’ on a case-by-case basis.

Impeded access between properties may prevent the movement of farm supplies (e.g. fuel, fertiliser), machinery, stock to market and grain at harvest onto/off properties. Landholders may be able to use boats or four-wheel drive vehicles, but heavier farm machinery and trucks may not be able to use the unsealed road network. This is highly dependent on timing and duration of flow.

Properties that do not directly front waterways may be isolated at higher flows. For example, a property may be tens of kilometres away from a high river, but a running local creek or flood runner may prevent access.

It should also be noted that access is not only impeded during the flow, but also through prolonged soil saturation after the flow has receded.

Inundated land

Major flood events have a significant economic impact on the area, and agricultural systems in most southern Murray–Darling Basin (the Basin) areas operate differently from the northern part of the Basin. Apart from crop losses and disruptions to human activities, grazing paddocks can lose productivity during an extended period. When slow-moving flood waters are combined with warmer weather events in September and October, ground cover (native and introduced) may be inundated for extended periods. Under such conditions, pasture species can rot and feed value may be lost until another growth phase in autumn.

Periodic flooding may be beneficial for some farming operations in specific areas; however, high frequencies of floods may render land unusable. High-frequency flooding may result in a ‘shift’ of plant species, with both native and introduced species finding it more difficult to tolerate this type of regime. Such changes may also elevate the spread of noxious weeds, including lippia, which has already made significant inroads to other floodplain areas in the Basin.

Rotational management systems and cropping in other areas may also be disrupted. For example, in rotational systems, some paddocks may be rested in spring and stock moved to river or timbered paddocks. A significantly changed flow regime will require alternate arrangements to be made to ensure the rotation maintains ground cover and allows seed set. Adequate, long-term forecasting of regulated flow events may assist in the planning of farming operations.

River paddocks or timbered country (often within the floodway) is regularly used as shelter for lambing ewes and off-shears (recently shorn sheep) to protect stock from cold and rain. Timing of a flow event may prevent this activity or result in stranded livestock. Adequate forewarning of an event may allow stock to be moved or for supplementary feeding to be undertaken. Landholders noted that, in many cases, the only sheltered country on a property is along the timbered waterways, so no alternative country is available to shelter stock at these critical times.

Every landholding and business is different. Some properties that are located on the high side of the river may experience very limited effects, whereas others both on the river and away from the streams may suffer far greater impacts. Any two neighbours will be hit differently.

Levees and floodplain management planning

The majority of levees in agricultural areas are privately owned. Levees are expensive to construct and maintain, and the construction methods, design standards and maintenance standards are highly variable across the reach. Landholders considered that if these levees are called upon to protect properties from regulated flows, there may be a need to strengthen or increase the height of existing levees, and that these amendments would need to comply with specifications in relevant floodplain planning policies. The community was clear that their view was that any costs associated with this work should not be borne by individual landholders.

NSW

Flood management plans have provided for an extensive network of designated floodways throughout the Edward-Wakool region that limit floodplain development. The use of levees to protect farms has been developed under the Central Murray Floodplain Plan. Construction of levees within designated floodways is prohibited by current New South Wales planning laws except under exceptional circumstances.

Many landholders in the New South Wales part of the reach made decisions **not** to build levees under the local floodplain management plans and were prepared to live with the **current** infrequent flood events. These properties may now be exposed to increased flooding (between winter and early summer) that may justify the construction of levees; however, they may be prevented from doing so given the relevant floodplain management plan.

Some new levees around the Perricoota–Koondrook Forest Flood Enhancement Project have been publicly funded, but other Living Murray assets such as Barmah–Millewa Forest do not have publicly funded levees. Environmental water released may then apply pressure to these private levees.

The existing levee network is extensive, comprising hundreds of approved and unapproved levees identified in the Central Murray Floodplain planning process. However in certain areas, the issue of unlicensed or unapproved levees remain problematic.

Flood waters from a variety of river sources can vary the impacts of individual flood events. For example, in the western area of the reach, water came overland at Benjaroop during the 2010–11 flood (around 28,000 ML/day at Barham and more than 30,000 ML/day at Stoney Crossing), which had not been previously seen given the flow was not very large. The overland flow was caused by the contribution of Victorian streams that were running high at the time, which when combined with Murray flows, produced unexpected, significant and damaging flooding in Victoria.

Victoria

The Draft Victorian Floodplain Management Strategy provides the basis for assessing flood risk and setting regional priorities. Catchment Management Authorities also act as Floodplain Management Authorities and have responsibility for preparing strategies for their regions including developing floodplain management plans. .

The Victorian levee management guidelines detail design principles and maintenance responsibility for public and private levee banks. At present the development of new levees is only considered in limited circumstances if they are considered necessary for environmental watering or to reduce the risks of a river changing course.

Frequency, timing, duration and predictability of proposed flows

The MDBA needs to be clear about the likely frequency, timing, duration and predictability of these increased flows.

The community cannot assess the full extent of negative impacts on their lives and businesses from the delivering this environmental water with any accuracy until such time as this information is provided. This information, together with more accurate maps taking into consideration contributing flows from other tributaries, is needed for informed assessment and comment.

Managing access during emergencies

There are many access roads throughout the region that cross creeks. If a flow was to impede access during a bushfire, then landholders are at risk of isolation or entrapment. The concern was that if access was impeded, then people may not be able to avoid or escape from a fire threat. Environmental flows within public forests in the latter part of the season (summer) can create fire management issues. Artificial watering events may wet up some sections, but the remaining forest and broader regional conditions may be dry and subject to fire risks. Under such scenarios, forest roads remain inaccessible as environmental watering events may not have fully receded.

Timing of environmental flows can also impact forest fire trail management. This can mean that early response to localised lightning strikes may be delayed, thereby increasing the likelihood that these events could turn into larger fire incidents. Properties adjacent to public forests receiving environmental flows may also be affected, as associated creek systems pass through private land. If the River Murray remains high for extended periods in the spring season, corresponding river/creek systems will also be higher and this may affect fire management during emergencies. Development of strategies to maintain access to private land is critical for fire prevention and firefighting events.

Potential for environmental damage

Some flow regimes may lead to increased riverbank erosion and slumping, and cause trees to fall into rivers. This may lead to redirection of flood flows and the mobilisation of sediment.

Increases in flood footprints will result in changes to current native vegetation assemblages, potentially drowning out existing river red gums and native vegetation. This may also extend river red gum re-growth into what is currently black box grassland and may have been native grassland before river regulation. Increased flows may also result in increased weed infestation along watercourses.

Close consultation with local communities can help to manage for the best environmental outcomes. Environmental deliveries need to account for the risk of fish kills, and avoid interfering with spawning of native fish and the production of large numbers of pest fish species such as carp. Increased carp numbers may also increase sediment levels in the water.

Water quality

There are potential affects to water quality arising from the delivery of environmental water. Increased flows could contribute to the risk of increased impacts of acid sulfate soils which occur in the reach. Hypoxic blackwater[5] events are also a concern that will need to be considered if delivering higher managed flows.

Groundwater recharge

Understanding the effects of salinity and groundwater management has been a considerable issue in the Wakool district. The community identified that infiltration through the bank profile and the hydraulic loading caused by prolonged flooding has a major impact on groundwater rise across most of the Wakool Shire. (See report by Wang, Khan and O'Connell that quantified the effect of rainfall on shallow groundwater table in the Wakool Irrigation District: NSW, CSIRO Land and Water, Griffith Laboratory 2003.)

[5] When organic material, such as leaf litter, decays in wetlands and waterways, it darkens the water — known as 'blackwater'. Blackwater and the decaying process is a natural and important nutrient cycling process. However, when organic material decays, it uses oxygen held in the water. Under the right conditions (warm water and high volume of organic material), too much oxygen can be taken from the water, causing a hypoxic blackwater event that can stress or kill aquatic species.

More than $600 million (15% government and 85% landholder cash and in-kind) were invested in land and water management plans in the district between 1995 and 2010. Many of the associated projects are still ongoing. Prior to 1990, more than $30 million was spent on establishing the Wakool Tullakool Sub Surface Drainage Scheme (WTSSDS). The aim of the scheme was to maintain the watertable at least 2.5 m underground. There is a belief that running these creeks above current levels will potentially void the work undertaken through the WTSSDS, leading to increased groundwater levels and a decrease in production on properties well away from the actual rivers.

Devaluation of the land asset

Landholders felt that land values were being lowered (already being reflected in local property sales) as people are now coming to realise the potential impacts that watering events might have. There was also the belief that if easements were to be sought as a mitigation measure, this would also contribute to the devaluation of land.

Landholders expressed strong concerns about the limitations of the MDBA's social and economic studies on the Basin Plan. Many community factors were not included in the studies; for example, third party property access, flooding issues or access to water entitlements. Also, there has been no assessment of the ability for irrigation entitlement holders to have continued access to their water entitlements, if river operations alter the ability of river pumpers to take water. This may mean raising and lowering river levels to meet new environmental flow requirements.

Public and private infrastructure

Bridges in the Wakool Shire will need replacement should the flows exceed their current capacity. Replacement bridges would need to be fit-for-purpose and account for the increased size and weight of agricultural machinery. Increased flows may also damage roads with this issue needing further exploration with councils.

There may also be a need to elevate some minor buildings and infrastructure, as well as raise pumps (for both irrigation, and stock and domestic supplies) on some properties as a result of higher flows. The extent of this issue depends on the frequency, timing and duration of the proposed flows.

Further, increased flows at certain heights and at specific times may necessitate the lifting of pumps at critical times within a property's cropping program. For example, a spring environmental flow event, which requires the lifting or raising of river pumps (out of the river), may coincide with the irrigation requirements of rice or winter cereal crops. This could result in missed crops and a potential significant loss of annual income.

Tourism

Rivers and waterways that can be accessed are important for tourism. Fluctuating river levels (both higher and lower) can affect local economies.

For example, fishing and waterskiing are significant tourist drawcards for towns like Deniliquin and Moulamein. If the beaches and boat ramps are submerged (or flows are too fast) at critical times, tourist numbers drop, with town economies consequently suffering.

Sporting facilities (including the golf course and low-lying sporting fields) in Deniliquin may be affected depending on the height of the proposed flows (more likely at the higher flow rate).

The social and economic impacts of red gum forest conversion to national parks was meant to be offset by increases in tourism, with suggestions by government officials that expected visitor numbers would increase up to 50,000. Although this figure is disputed by local communities, tourism in forest areas may be affected by the timing of environmental releases. Many of the forest roads would be cut at fairly low levels.

Many local roads, including the one between Tocumwal and Mathoura, pass through the forest, and environmental flows across lower road crossings may affect regular traffic and tourism access.

Adequacy of funding

Previous water and natural resource reforms have divided the community. There has been a lack of transparency, the 'rules' changed and the process was unclear. There were 'winners and losers', which has made the community wary of funding opportunities like the Strategy.

> *Work with us, don't use the $200 million to further divide our community!*
> Community member, 2013 Barham CMS meeting.

There is a strong view that $200 million to address constraints is inadequate for the Yarrawonga Weir to Wakool Junction reach, let alone six additional reaches across the Basin. There are hundreds of crossings and low-lying bridges in the western part of this reach (Wakool Shire).

Potentially, affected landholders were keen to understand the detail around how they would be involved in the 'feasibility' assessment phase. Also, there is a need to understand whether the $200 million funding allowed potentially affected landholders to obtain professional advice and support to make decisions about constraints projects.

Environmental watering

There was a broad concern that the community had very little knowledge or involvement in environmental watering that happened throughout the reach. This included limited understanding of what environmental watering was specifically trying to achieve (e.g. how many birds, how many fish), how it would be delivered, how the MDBA would know if the objectives had been met and if environmental water targets are missed, and would the MDBA keep pursuing the objectives until they were met? There was a further concern that the various government agencies (state and Australian) responsible for environmental water were not talking with each other. There are, however, a number of local environmental watering projects that see strong participation from locally interested landholders.

In the interest of transparency, there needs to be clear, concise information provided and discussed with the community on the volume, height and dates of environmental flows before they commence.

> *We know environmental water is here and we need to work together to get the best outcome for everyone.*
> *Community member, 2015 CMS meeting*

Communities asked for increased transparency and local involvement in management of environmental flows. This included community participation in setting environmental targets for local areas. This would include developing original benchmarks to determine what the environmental baseline conditions are, and so that future change can be monitored.

Niemur River looking downstream from the Moulamein-Barham Road. *Photo: Phil Townsend, MDBA*.

Additional considerations

The community wants to know how the MDBA will deliver the environmental flow targets used to support the development of the Basin Plan within the 2,750 GL/year recovery target without third party impacts.

Early MDBA advice had stated that overcoming constraints was principally associated with the delivery of the additional 450 GL of water recovery, though implementation of on-farm efficiency measures (i.e. 3,200 GL/year recovery target). Local communities have, however, identified third party impacts associated with the delivery of water recovered to support the Basin Plan (i.e. the 2,750 GL/year recovery target). The community expressed even stronger concerns that an additional 450 GL of water recovery would lead to even higher third party impacts, citing the impacts associated with the recent flow trials as low as 18,000 ML/day (within the 2,750 GL/year target) at Yarrawonga.

Mosquito-borne disease implications — Ross River fever, Murray Valley encephalitis and other mosquito-borne diseases — thrive in the human population after each flood event. Stagnant water provides optimal breeding for mosquitoes. The economic and social implications of this need to be assessed, as there are no vaccines for these diseases.

There were many additional potential effects recorded, such as the damage to private fencing, the effect on non-native fish species (e.g. European carp), and social and economic impacts on regional economies from the higher-level environmental flow targets set under the Basin Plan. A comprehensive range of issues would need to be examined in more detail if this reach was identified to move into feasibility.

The Edward–Wakool River system is increasingly recognised as a valuable ecological area for native aquatic species. Local communities have a strong history of collaboration with government agencies in securing and managing environmental flows for regional forests, wetlands and the Edward–Wakool system. The complex nature of this reach confirms the need to have strong local component in decisions around environmental flows.

Local government, regional and state government agencies and corporations

A number of local government councils, regional and state government agencies and corporations were invited to help in the development of the Strategy. These organisations included the NSW Office of Water, State Water Corporation, Murray Local Land Services, the NSW Office of Environment and Heritage, NSW National Parks, and the Wildlife Service and Forestry Corporation.

Staff from agencies participated in meetings between 2013 and 2014, and facilitated the refinement of hydrologic data, flood planning information, local- and regional-scale effects of different flow rates, and information on environmental assets. Where supplied, this information and data have been incorporated into the analyses for this reach.

Townships in Victoria and New South Wales

There are minor effects at flows of 20,000 and 35,000 ML/day. At 50,000 ML/day, some towns need to undertake flood management activities. At flows of 77,000 ML/day, some towns are in or approaching moderate flood rating, and are required to implement flood mitigation activities. A number of low-lying bridges in the west that enable property access (where low-lying bridges are currently unserviceable) may be inaccessible.

The MDBA worked with local councils and flood management agencies, and used current floodplain management assessments in New South Wales and Victoria to review potential effects of increased flows. New South Wales councils that were directly involved in this reach included Berrigan, Murray, Conargo and Wakool shires, and the Deniliquin Council. Understanding flood effects for Victorian townships was coordinated through the North Central, Goulburn–Broken and Mallee catchment management authorities (CMAs). Data were focused on developing a general understanding of the flows being studied, and sought to identify potential effects and specific management actions required to deal with these effects. A detailed table of potential effects at each flow rates is provided in Appendix 2.

In all cases, the flows being examined for this region are well below the 100-year average recurrence interval (ARI) event for towns within this reach.[6] Urban flood protection levees generally provide protection up to the 100-year ARI for townships located immediately adjacent to rivers (GHD 2014a, 2014b, 2014c). The exception is Echuca, which has a flood protection levee built to the 30-year ARI, plus a 300 mm freeboard (C. White, NCCMA, pers. comm). As none of the flows being examined by the Strategy are near the 100-year ARI and local

[6] The average recurrence interval (ARI) is the long-term average number of years between the occurrence of a flood as big as or larger than the selected event. For example, a flow rate at the 100-year ARI will occur on average once every 100 years.

governments have, in many areas, limited development to the 100-year ARI, none of the flows being examined for the Strategy result in damaging effects for any of the townships for which data have been collected.

Some townships, however, are affected at all flow rates in some way. There are potential considerable effects at the highest flow rate being studied for the Strategy — 77,000 ML/day (Tocumwal). At around this flow rate, low-lying areas in the townships of Tocumwal, Deniliquin and Moama are inundated, and some townships are required to undertake flood management activities. At flows of 77,000 ML/day, Deniliquin Council would be required to relocate public amenities (semi-portable) and commence closure of levee outlets, and some landholders would be required to seek alternate routes to access their properties.

Fringe areas of a number of caravan parks are also likely to be affected at flows of 77,000 ML/day (Tocumwal). Many of the caravan parks in the region are located immediately adjacent to rivers, and have park areas that provide direct access the river and marinas, and/or are reserved for camping or temporary caravanning. Adequate warning of an impending flow may be an effective strategy to enable local preparation to occur. Specific discussions with individual caravan park owners/managers would be required to develop a detailed understanding of potential effects and mitigation measures.

Public infrastructure — bridges and roads

Specific desktop analyses paid particular attention to potential effects on bridges and roads. Discussions with New South Wales councils confirmed that major infrastructure — including sealed roads and bridges on main thoroughfares — have been built, or are currently affected only at or above the 100-year ARI. There was only one instance where improvements were required on a major road (culverts to replace existing fords) and this was included in prefeasibility costing. Discussions with North Central CMA and Goulburn–Broken CMA suggested there would very little effect on major thoroughfares for Victorian parts of the reach, as levees protect significant infrastructure located in flood-prone areas.

A small number of low-lying timber bridges in the western part of the reach (within the Wakool Shire) were identified as potentially affected by the flows being studied. These bridges typically provide a primary means of access to one or two properties. Costing for the replacement of these bridges was incorporated into the prefeasibility analysis for this reach. Discussions with the Wakool Shire indicated some of these bridges are already part of the Wakool Shire’s bridge replacement program.

A number of unsealed roads were potentially affected at the higher flow rates being examined. These roads were mainly associated with recreational reserves and public lands; however, a small number were likely to provide principal access to private land. Improvements to potentially affected unsealed roads were incorporated into costing for prefeasibility.

Ford on Picnic Point Rd in Barmah–Millewa Forest. This crossing is unlikely to be affected by flows being examined for this reach. *Photo: Terry Korodaj, MDBA*.

Recreational and tourism effects

Recreational use of the rivers can be very high in localised parts of this reach; however, most activities tend to occur during warmer months, from the long weekend in October to Easter weekend. If higher flows patterns were delivered in winter–spring, there is likely to be little negative effect on recreational use of the rivers.

Key recreational activities include fishing, waterskiing and camping. In some areas, river users are dependent on boat-launching facilities such as boat ramps. At some of the flow rates being examined, boat ramps become isolated or inundated, and cannot be used. Other areas that may be affected including bush-camping facilities and associated access tracks. Houseboat operations may be affected at the highest flow rate being examined. Some houseboat operators may close their operations to less-experienced houseboat users.

Secondary impacts to businesses such as eateries and accommodation may also need to be considered if recreation and tourism traffic decreases from changes in flows.

More detailed investigations into impacts of increased flows on specialised activities such as golf courses, caravan parks etc will be conducted in 2015.

Tocumwal Beach on the River Murray at the Tocumwal township. These beaches will potentially be affected by increased regulated flows through this reach. *Photo: Terry Korodaj, MDBA*.

Murray Irrigation Limited

There are no effects reported at flows of 20,000 and 35,000 ML/day. At flows of 50,000 ML/day (nine days), Murray Irrigation Limited are required to open flood gates on their northern canal system. At flows approaching 77,000 ML/day, an additional three flood gates need to be opened and irrigation system demands met. Additional work is required to understand specific effects on delivery and drainage canals as well as water accounting considerations.

Murray Irrigation Limited (MIL) is a not-for-profit unlisted public company that provides irrigation water and associated services to approximately 1,200 family farm businesses over an area of 748,000ha through 3,000km of channels in the NSW southern Riverina.

The MDBA met with MIL's water distribution manager and water distribution staff in 2013 and 2014. Discussions focused on the broad effects and management actions required to enable the flows being examined for the Strategy. Key activities that MIL are required to perform at the flows being considered include the removal of flood gates and closure of escapes. These activities are a legal requirement to enable the free passage of flood water and prevent backwater effects. These actions also help to protect water infrastructure and to ensure water supply to customers.

The on-site works are triggered following a continuous nine-day flow of 50,000 ML/day (at Tocumwal, or 20,000 ML/day at Deniliquin). The work is logistically intense, requiring heavy machinery and work crews to remove the flood gates and then re-instate the flood gates when the event has passed. This can take from 2–5 working days, depending on access, using two work crews. Additional staffing would be required to maintain existing operations.

Flows of just over 77,000 ML/day (Tocumwal, or around 50,000 ML/day at Deniliquin) require similar work to be carried out at nine additional sites. Additional resources, including machinery and work crews, are also required. Management activities at the 77,000 ML/day (Tocumwal) flow rate are complicated by access limitations imposed by the increased area of inundation. In some cases, crews are required to travel up to 80 km to enable closure of single escapes, which results in additional resource requirements.

In addition, access to MIL infrastructure is provided through private landholdings and is based on informal agreements. Increased flow rates less than 50,000 ML/day (Tocumwal) may also impact the ability of MIL staff to access these landholdings in order to operate infrastructure. Depending on the timing and nature of an event, normal day to day access to infrastructure may be impacted, leading to additional travel time and associated costs. Further work is needed to examine increased operating costs for MIL as a result of this increased workload.

Catchment conditions (wet or dry) alter irrigation system demands and consequently affect staff availability to conduct the flood operations described above. If the catchment is dry, irrigation demand will be high, and access to staff and equipment may be limited. This lack of staff and equipment may jeopardise ‘normal’ irrigation services if vehicular access is also impeded by overland flows.

Accountability of water into the MIL system for deliveries on-farm and through accredited escapes is a key component of MIL’s business. Undertaking flood mitigation actions as described above may complicate MIL’s ability to accurately account for water into and out of the system. Appropriate accounting arrangements for water into and through MIL’s system in response to higher regulated flows requires further investigation.

Regulated releases at high flow rates could potentially result in filling of drainage canals and irrigation channels. MIL raised concerns over the legal liability of any impacts caused on landholders by potential backflow events, or through passing of managed environmental flows in general.

More detailed work is required to understand the potential effects of higher flows on MIL form a whole of business perspective.

Forestry Corporation of NSW

Discussions with Forestry Corporation of NSW identified a number of potential effects to forestry operations, particularly in regard to Koondrook, Perricoota and Campbell’s Island state forests. These effects are mostly driven by an increased frequency of lower flows interrupting forestry operations. Despite these effects, the overall health and productivity of the forest is likely to increase as a result of higher flows.

Increased regulated flows at the lower flow rates being studied (20,000–50,000 ML/day at Tocumwal) would prevent access to ‘lower’ parts of the forest, ‘pushing’ forestry operations to ‘higher’ areas. Changes in operation as a result of more frequent flow events may incur additional costs through; crew downtime, loss of trained staff due to intermittent work availability, development of additional harvesting plans, marking additional areas and supervising shift crews. Concerns were also raised about exhausting timber resources located in higher areas, limiting continuity of supply.

Track maintenance costs may be also increased if flow frequencies are high. There may be additional activity associated with pumping to drain roads as well as cost of additional crossings to maintain access to harvesting operations.

Broad-scale or regional forestry operations have the potential to be disrupted for flows of 77,000 ML/day (Tocumwal). It is thought that operations will be affected at a number of additional sites across the region and this may have the potential to disrupt markets.

Further work is required to better understand the potential effects of higher flows and associated mitigation options.

Timelines for the Constraints Management Strategy

At a glance

Based on information collected to develop this reach report, Ministers made a decision in late 2014 about what further work was needed to better understand the benefits, impacts and costs associated with the flow rates being investigated. The decision was not a green light to actually build, do or change anything about how rivers are currently managed.

This reach report, along with further work conducted in 2015 will contribute to the development of a Constraints Management Business Case proposal for the Yarrawonga Weir to Wakool Junction reach.

Based on the Business Case, Ministers will decide by the end of June 2016 whether or not to proceed to implementation, and if so, at what flow rate. No increased flows will be delivered unless a decision has been made to move to implementation and all mitigation measures are in place.

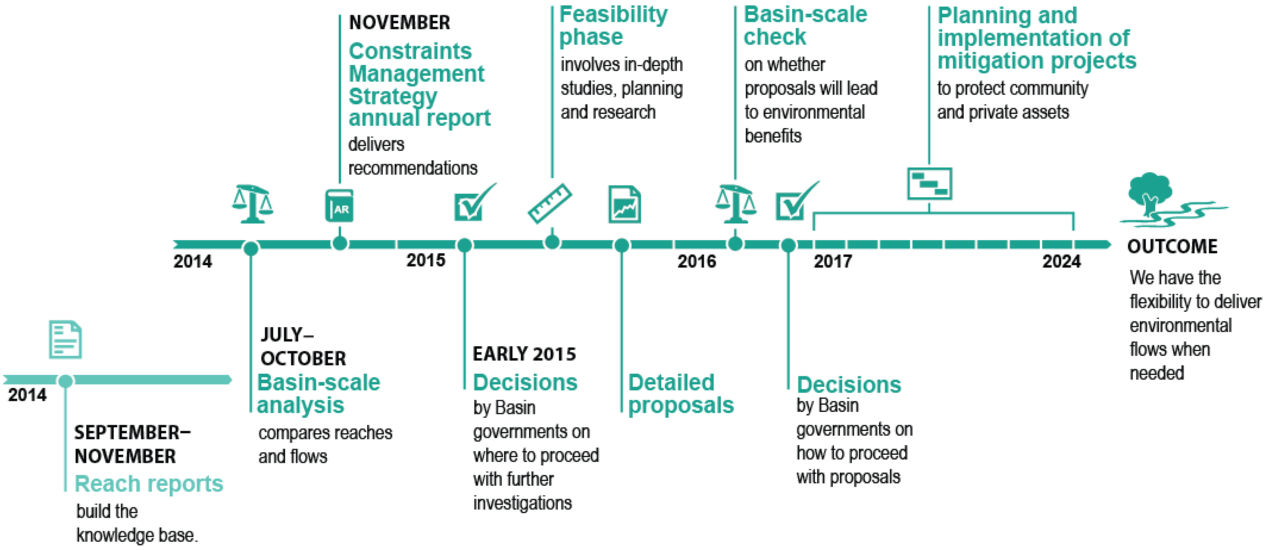


Figure 12: Phases of the Constraints Management Strategy

2014 Phase 1 - Prefeasibility

Phase 1 of the Strategy was about collecting information about the management and effects of higher flows and is just the start of a much longer process. The publication of this reach report marks the completion of Phase 1. The process for pre-feasibility and how the reach report was developed is shown in Figure 13.

During this phase, MDBA:

- investigated options to modify constraints, looking at different potential flows
- assessed the effects of these changes, including talking to landholders and communities about how different flows might affect them
- identified options to avoid or mitigate inundation effects (e.g. building bridges, upgrading roads or buying easements)
- identified areas requiring further investigation

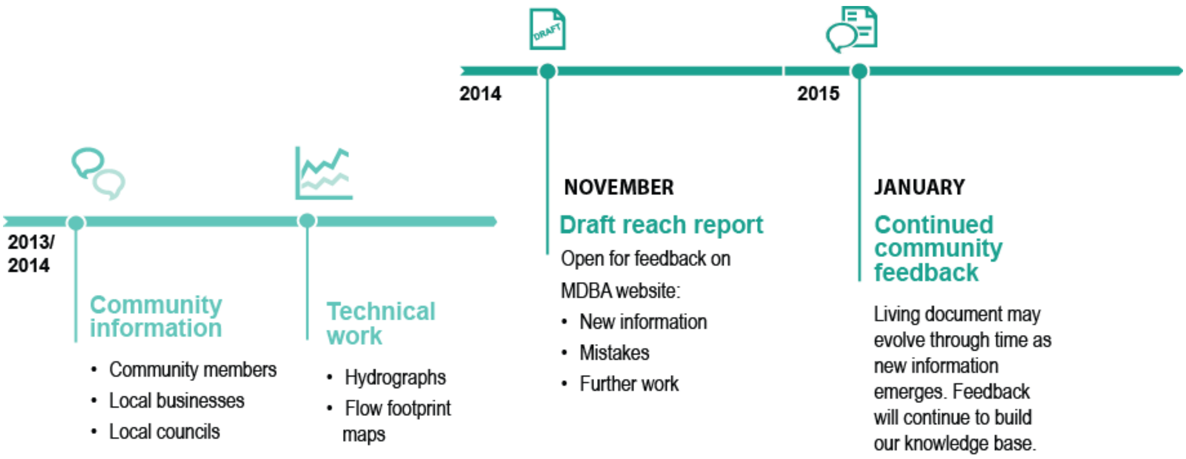


Figure 13: Pre-feasibility phase and reach report development

Information for the Yarrawonga Weir to Wakool Junction reach was then summarised together with information from the six other areas into the Constraints Management Strategy Annual Progress Report, which provided recommendations to Basin ministers. Ministers were also provided with the more detailed reach reports for each key area of constraints investigations.

Basin ministers (state and federal) agreed in late 2014 that detailed investigations should proceed for higher managed flows in all seven key focus. In some cases it was decided to reduce the highest flow rates being investigated: in this reach the maximum flow rate being investigated in 2015 is now 65,000 ML/day.

Decisions made at the completion of Phase 1 were commitments to undertake further studies, not a commitment to go ahead with planning and implementation of mitigation measures to allow higher managed flows.

Further work needed

Community members in the Yarrawonga to Wakool reach identified further work that needed to be done in order to feel comfortable that risks associated with delivering higher flows could be adequately addressed.

Risks and issues discussed in this report will be further investigated in Phase 2 – Feasibility and Business Case development. The key issued raised and processes to address those issues have been outlined in Appendix 3 Key issues register.

2015-16 Phase 2 – Feasibility and Business Case development

The Australian Government Department of the Environment has made funding available to provide the MDBA and the states with the resources needed to conduct detailed studies and prepare business cases for each of the key focus areas.

In Phase 2 of the Strategy, MDBA and Basin states will:

- do more detailed hydrologic analysis to better understand the flow rates and inundation extents being investigated
- further assess inundation impacts and options to mitigate those impacts
- improve cost estimates
- undertake furtherz community consultation

- develop business cases to submit to Ministers based on the information collected.

MDBA will lead investigations in the River Murray key focus areas on behalf of Basin states. An integrated package of constraints business cases for the three River Murray key focus areas — Hume to Yarrawonga, Yarrawonga Weir to Wakool junction, and South Australian River Murray — will be finalised by November 2015

Information in the draft business cases will be made available to the Edward-Wakool Advisory Group and other stakeholders for comment before being finalised.

The final Yarrawonga Weir to Wakool Junction Constraints Measure Business Case will be submitted by the NSW government to Ministerial Council for decision.

2016–24 Phase 3 — Planning and implementation

State and federal governments will decide by mid-2016 about whether to go ahead with easing constraints (planning and implementing mitigation measures that then allow higher managed flows). This decision will be based on the information contained in the business cases, such as environmental gains, whether any effects on communities can be overcome, and the costs involved.

If constraint measures move ahead to planning and implementation (mid-2016 to 2024), it is likely the states will undertake this work. Any works to be carried out would start in 2017. The implementation phase between 2017 and 2024 will put protective works and measures in place to mitigate or offset third party impacts. It is not until protective works are in place that overbank flows will become possible.

Post 2024 Higher managed flows will only be possible when packages of mitigation options are fully implemented

It is essential that measures are in place to mitigate the adverse effects on private landholders and community assets before any increased flows are delivered.

The MDBA has commissioned independent consultants to develop a consistent and standardised method to cost mitigation measures. The MDBA is concentrating on estimating the indicative costs of mitigating effects of increased regulated flows on private land and what infrastructure upgrades (roads and bridges) might be needed in the seven different regions of the Basin. However, these are not the only types of mitigation activity that may be needed, and further engagement with the community throughout the implementation phase will assist in determining the right combination of mitigation measures to meet local needs.

Appendix 1 Flow rates being examined for the reach

These flow rates were used to match corresponding inundation or flood footprints by CSIRO in the development of RiM-FIM modelling for this reach, June 2014.

Table 4: Downstream flow rates and associated river gauge heights for flows being examined for the Constraints Management Strategy

Location	Gauge	For flows at Tocumwal (409202)			
River Murray	Yarrawonga D/S (409025)	22,000[a] (3.0 m)	36,000[a] (4.2 m)	52,000[a] (5.2 m)	82,000[a] (6.4 m)
River Murray	Tocumwal (409202)	20,000 (3.5 m)	35,000 (4.8 m)	50,000 (5.7 m)	77,000 (6.4 m)
River Murray	Barmah (409215B)	11,000 (3.3 m)	20,000 (5.0 m)	29,000 (6.4 m)	33,000 (6.8 m)
River Murray	Torrumbarry D/S (409207)	26,000 (6.4 m)	37,000 (7.2 m)	40,000 (7.3 m)	58,000 (7.8 m)
River Murray	Barham (409005)	22,000 (5.5 m)	25,000 (5.8 m)	28,000 (6.0 m)	35,000 (6.2 m)
River Murray	Swan Hill (400204)	20,000 (3.4 m)	24,000 (3.9 m)	25,000 (4.1 m)	32,000 (4.7 m)
River Murray	Wakool Junction (414200)	24,000 (6.2 m)	33,000 (7.5 m)	54,000 (9.3 m)	82,000 (10.3 m)
Edward River	Deniliquin (409003)	7,500[a] (n/a)	14,000[a] (4.2 m)	23,000[a] (5.2 m)	48,000[a] (7.1 m)
Edward River	Stevens Weir (409023)	5,000 (3.5 m)	10,000 (5.0 m)	15,000 (5.9 m)	26,000 (7.1 m)
Edward River	Liewah (409035)	5,000 (4.3 m)	7,000 (5.0 m)	8,000 (5.3 m)	17,000 (7.2 m)
Niemur River	Barham-Moulamein Rd (409048)	3,000 (4.2 m)	7,000 (5.3 m)	8,000 (5.5 m)	19,000 (6.4 m)
Wakool River	Deni-Wakool Rd (409072)	1,000 (2.9 m)	2,000 (3.5 m)	3,000 (3.9 m)	5,000 (4.3 m)
Wakool River	Stoney Crossing (409013)	7,000 (3.6 m)	17,000 (5.7 m)	28,000 (6.8 m)	43,000 (7.9 m)

Location	Gauge	For flows at Tocumwal (409202)			
River Murray + Goulburn River	McCoy's (405232) + Barmah (409215)	28,000[b]	41,000[b]	50,000[b]	60,000[b]
River Murray + Goulburn River + Campaspe River	McCoy's (405232) + Barmah (409215) + Rochester (406202)	33,000[b]	50,000[b]	52,000[b]	66,000[b]

a These values are estimated by correlation of historic flows using average travel time. Data for these gauges were not used in the development of inundation maps, but have been provided to assist interpretation of the flows being studied.

b These are not representative of actual flows at specific gauges but represent the combined flows from multiple gauges. This approach was used to reflect backwater effects and to capture tributary in-flows associated with River Murray flows.

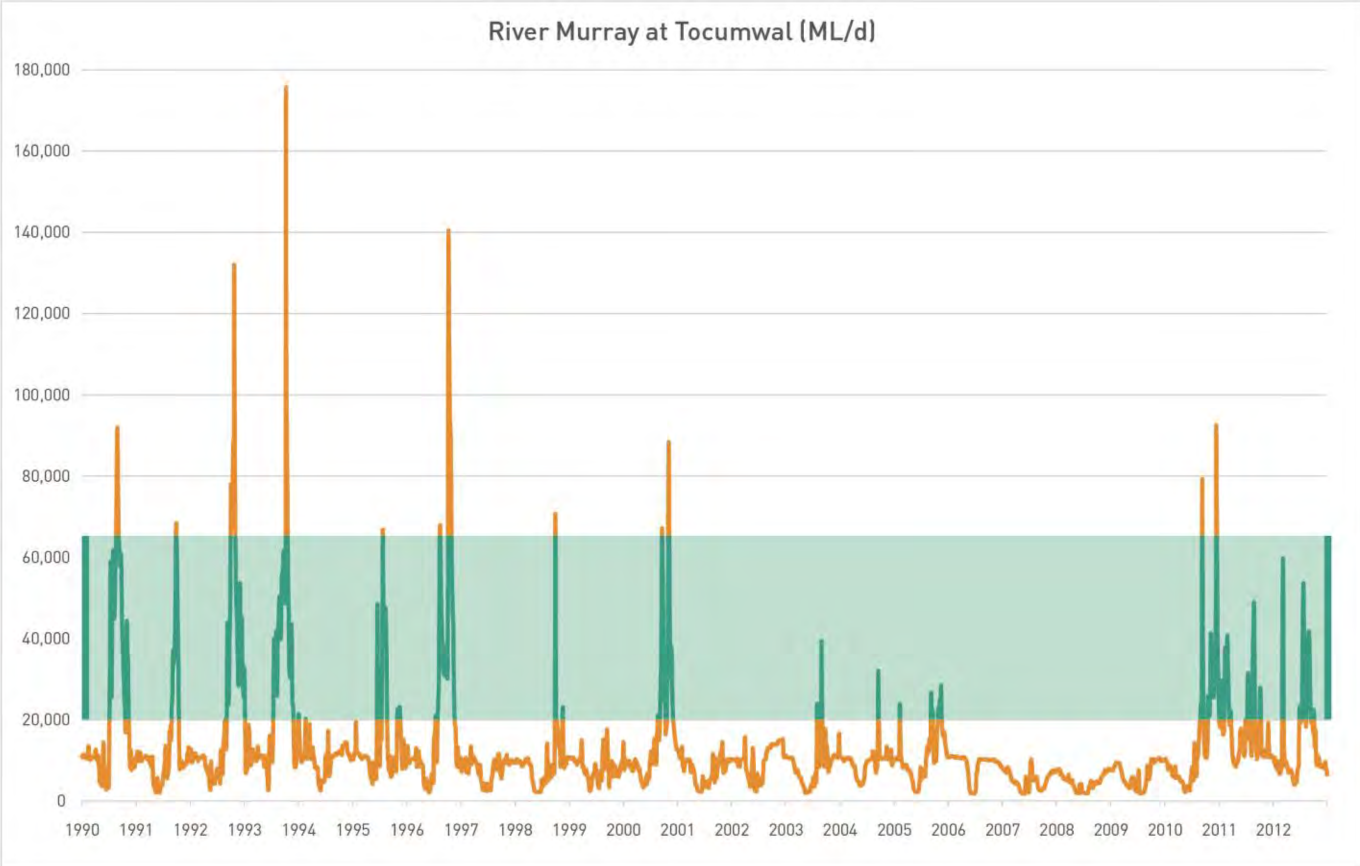


Figure 13. Average daily water flow in the River Murray at Tocumwal (gauging station 409202), January 1990 – December 2012

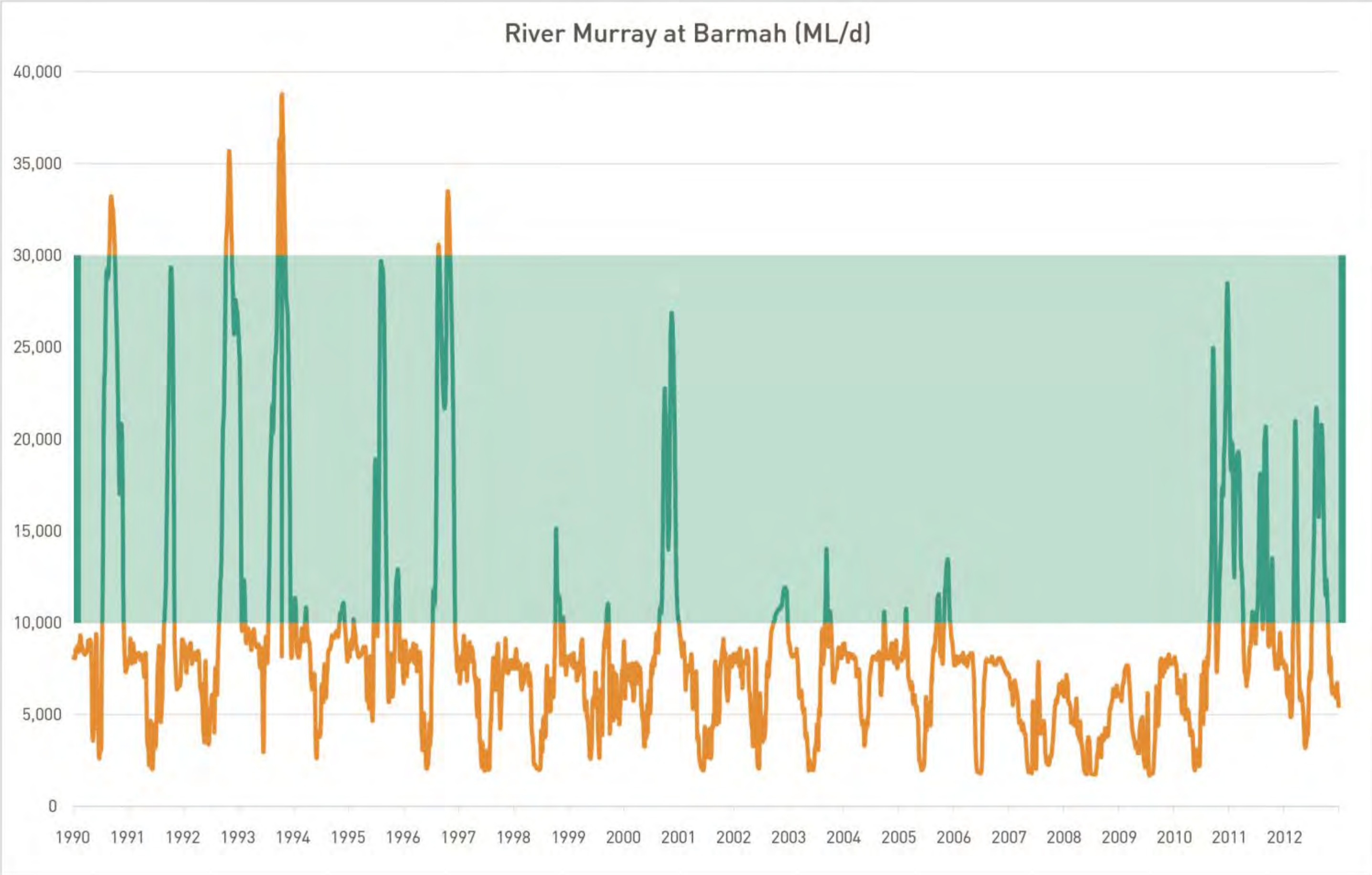


Figure 14. Average daily water flow in the River Murray at Barmah (gauging station 409215), January 1990 – December 2012

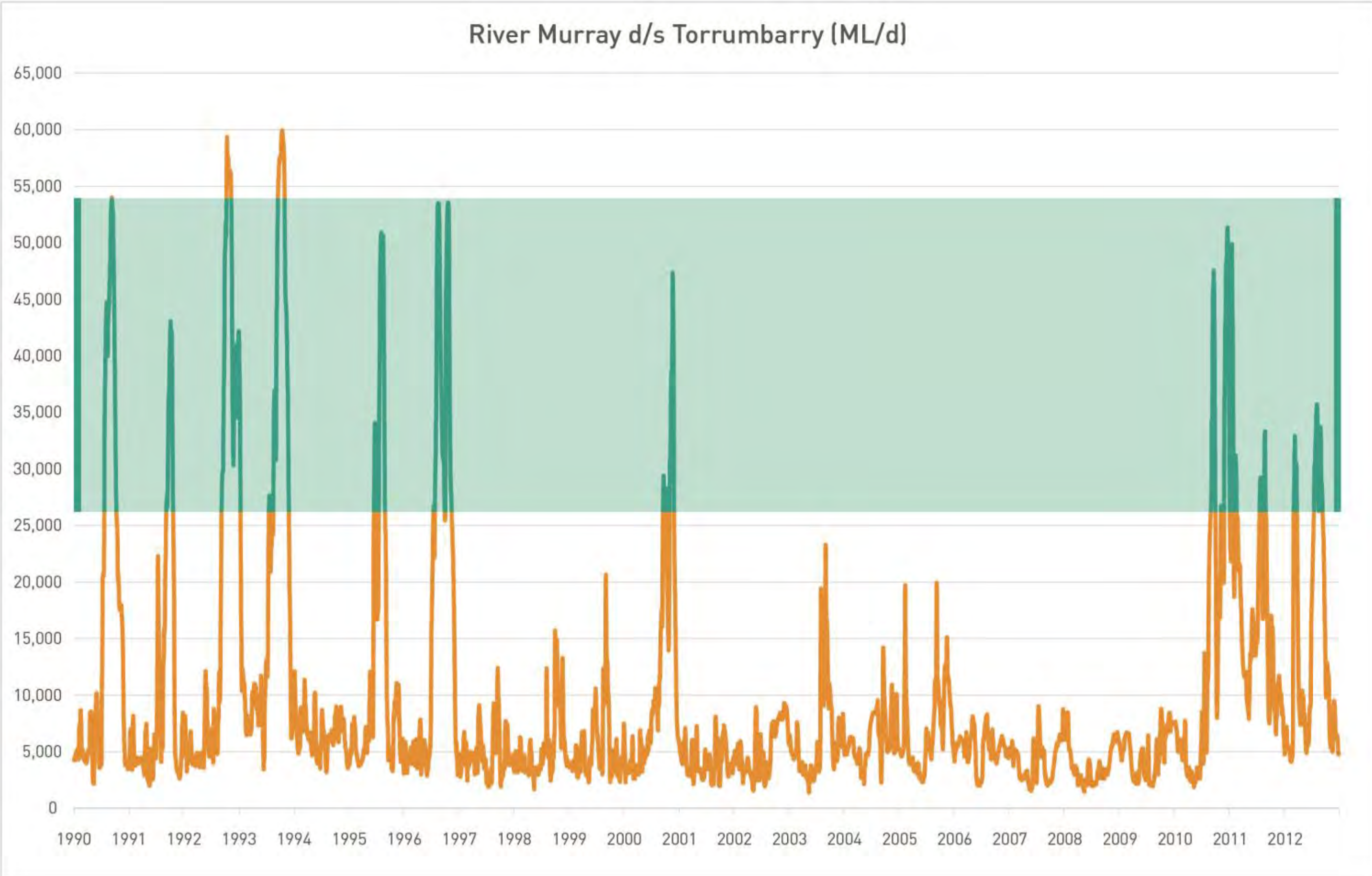


Figure 15. Average daily water flow in the River Murray d/s Torrumbarry Weir (gauging station 409207), January 1990 – December 2012

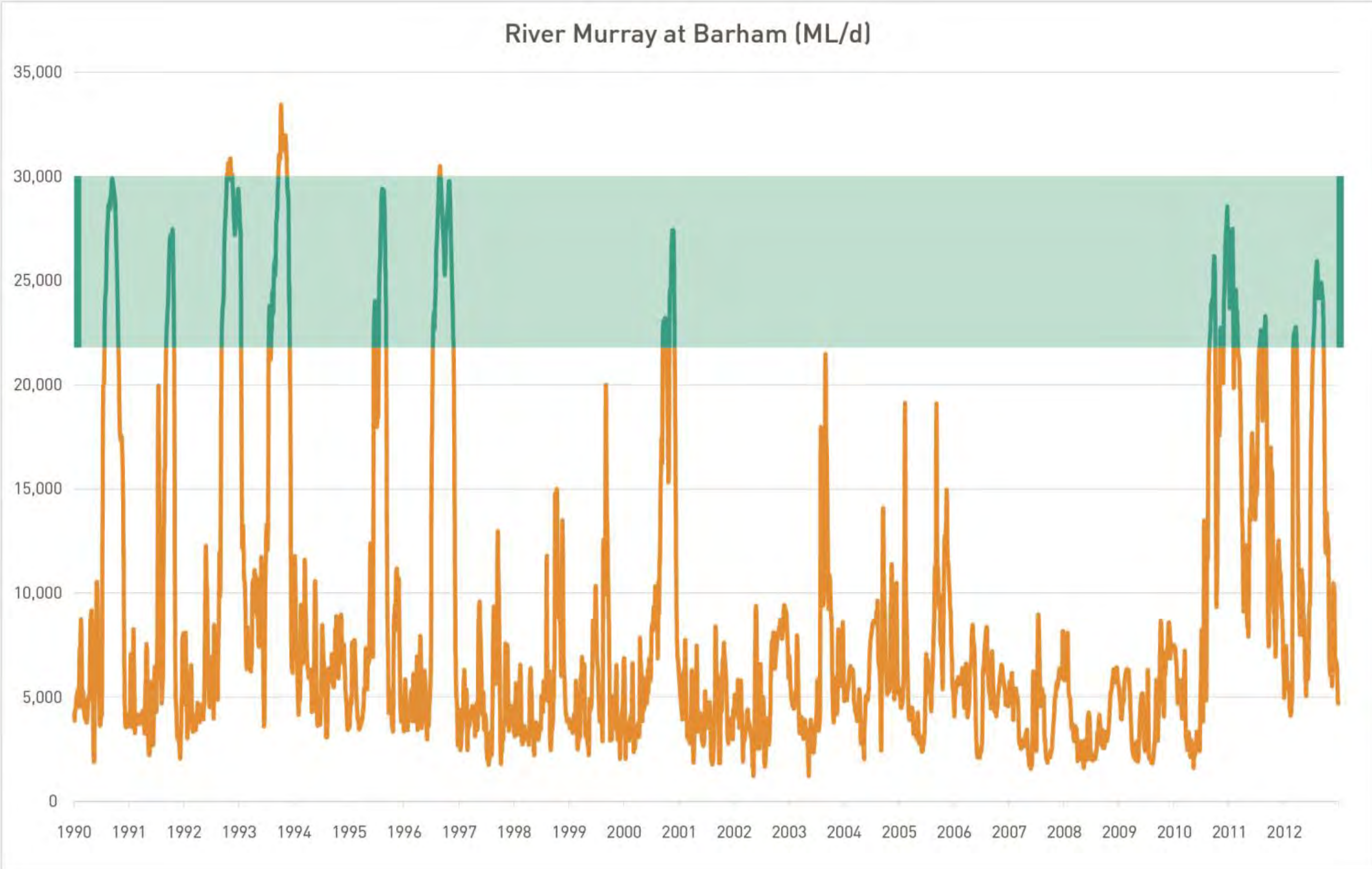


Figure 16. Average daily water flow in the River Murray at Barham (gauging station 409005), January 1990 – December 2012

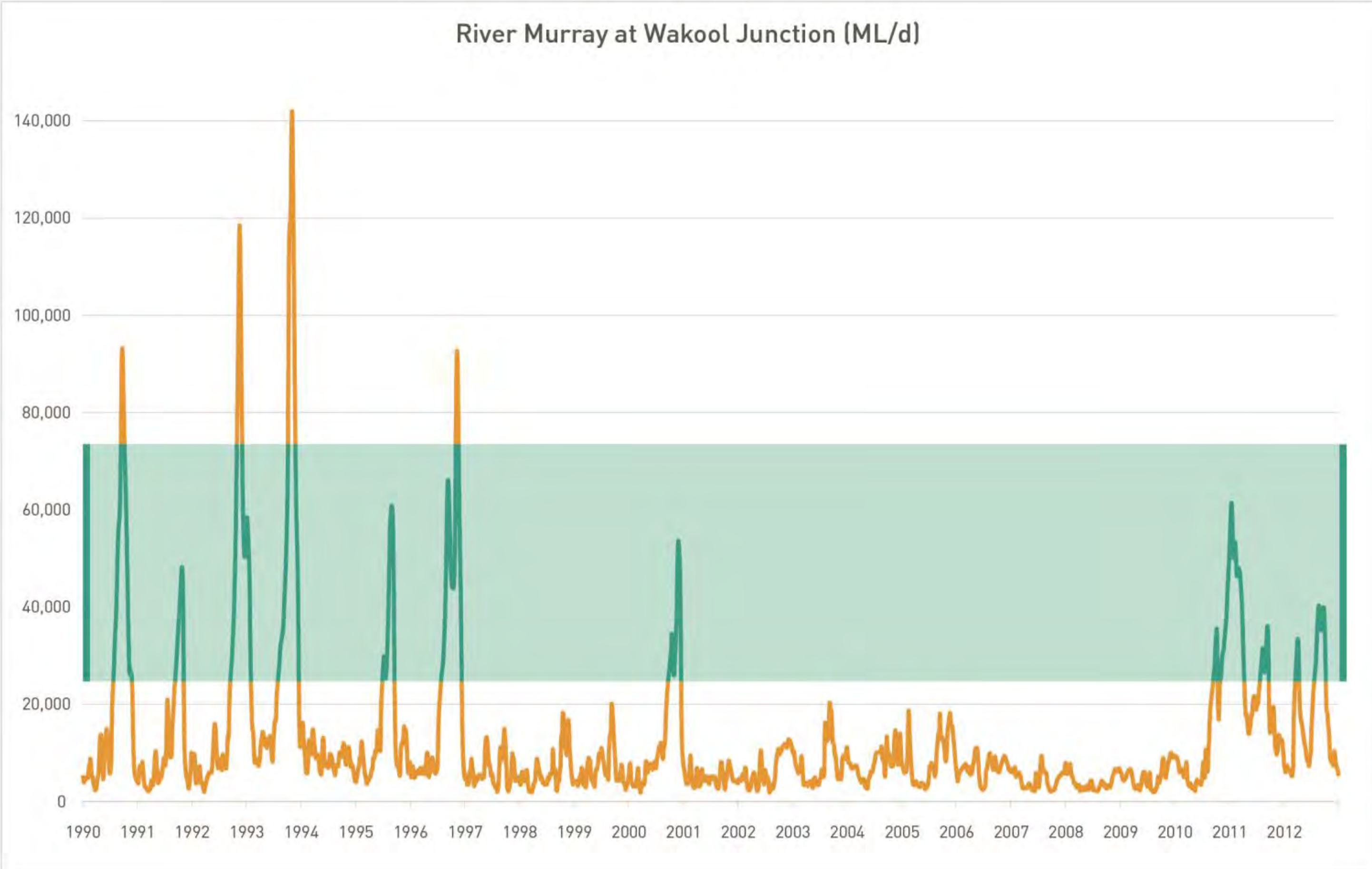


Figure 17. Average daily water flow in the River Murray at Wakool Junction (gauging station 414200), January 1990 – December 2012

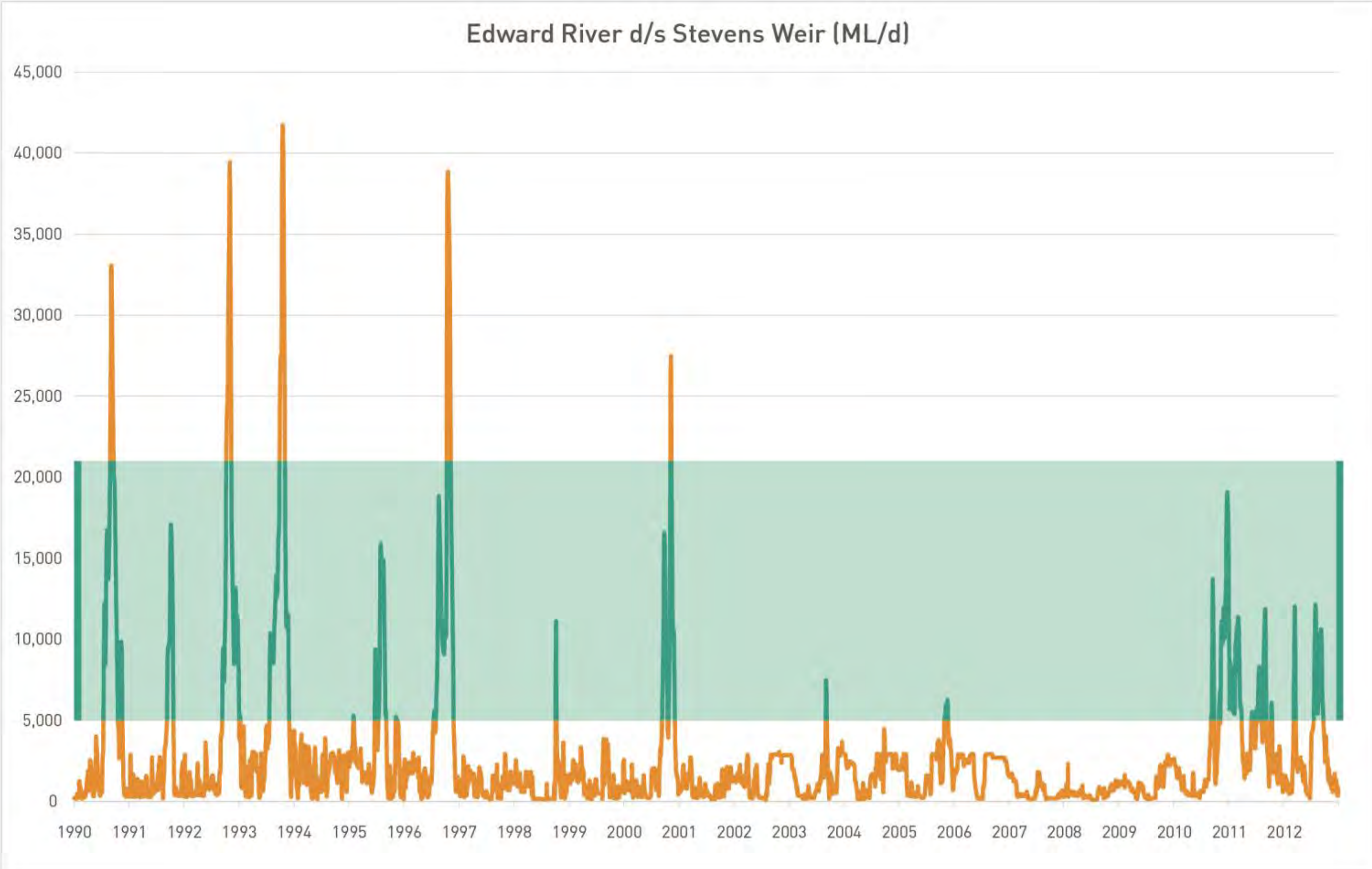


Figure 18. Average daily water flow in the Edward River downstream of Stevens Weir (gauging station 409023), January 1990 – December 2012

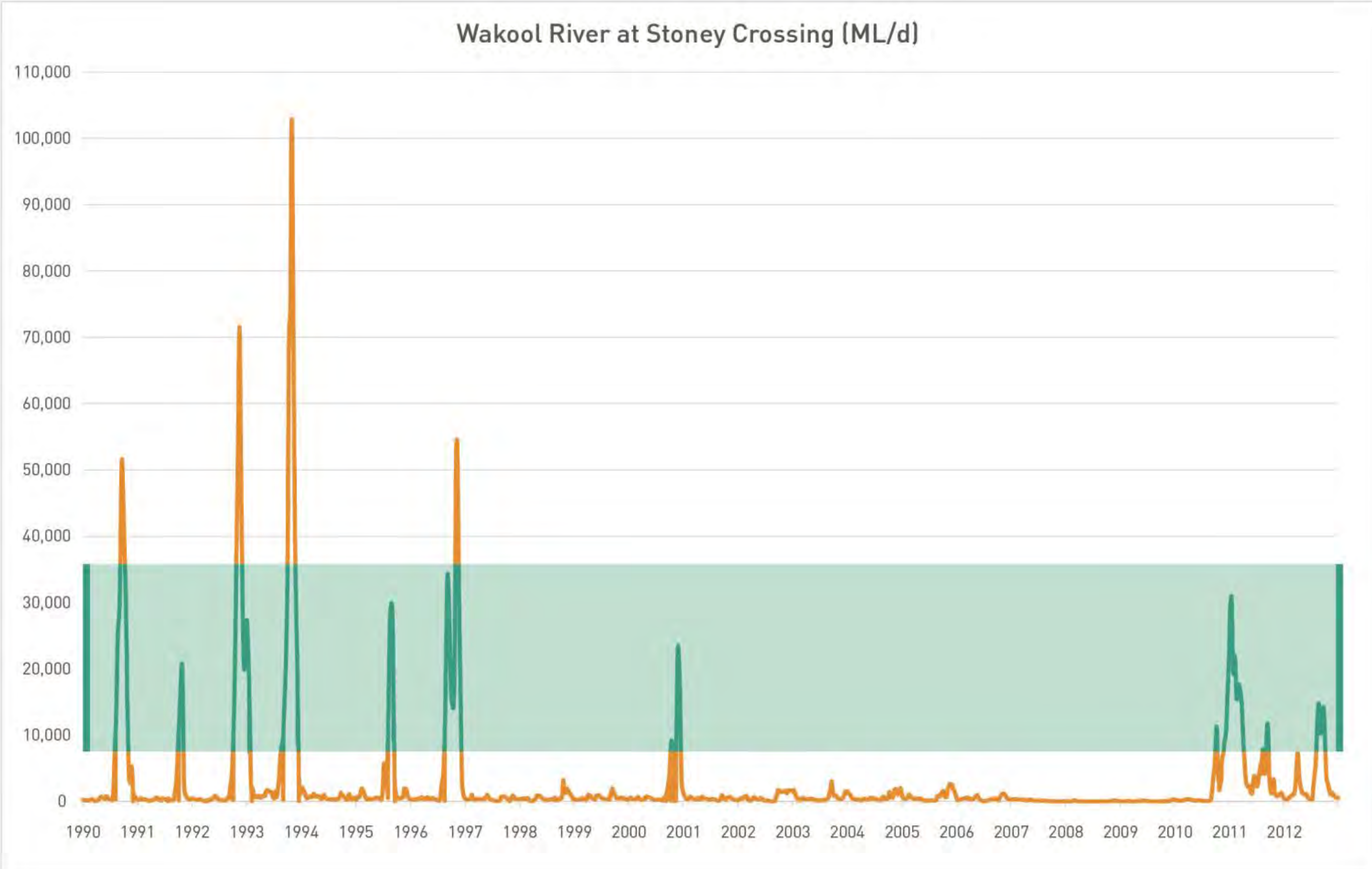


Figure 19. Average daily water flow in the Wakool River at Stoney Crossing (gauging station 409013), January 1990 – December 2012

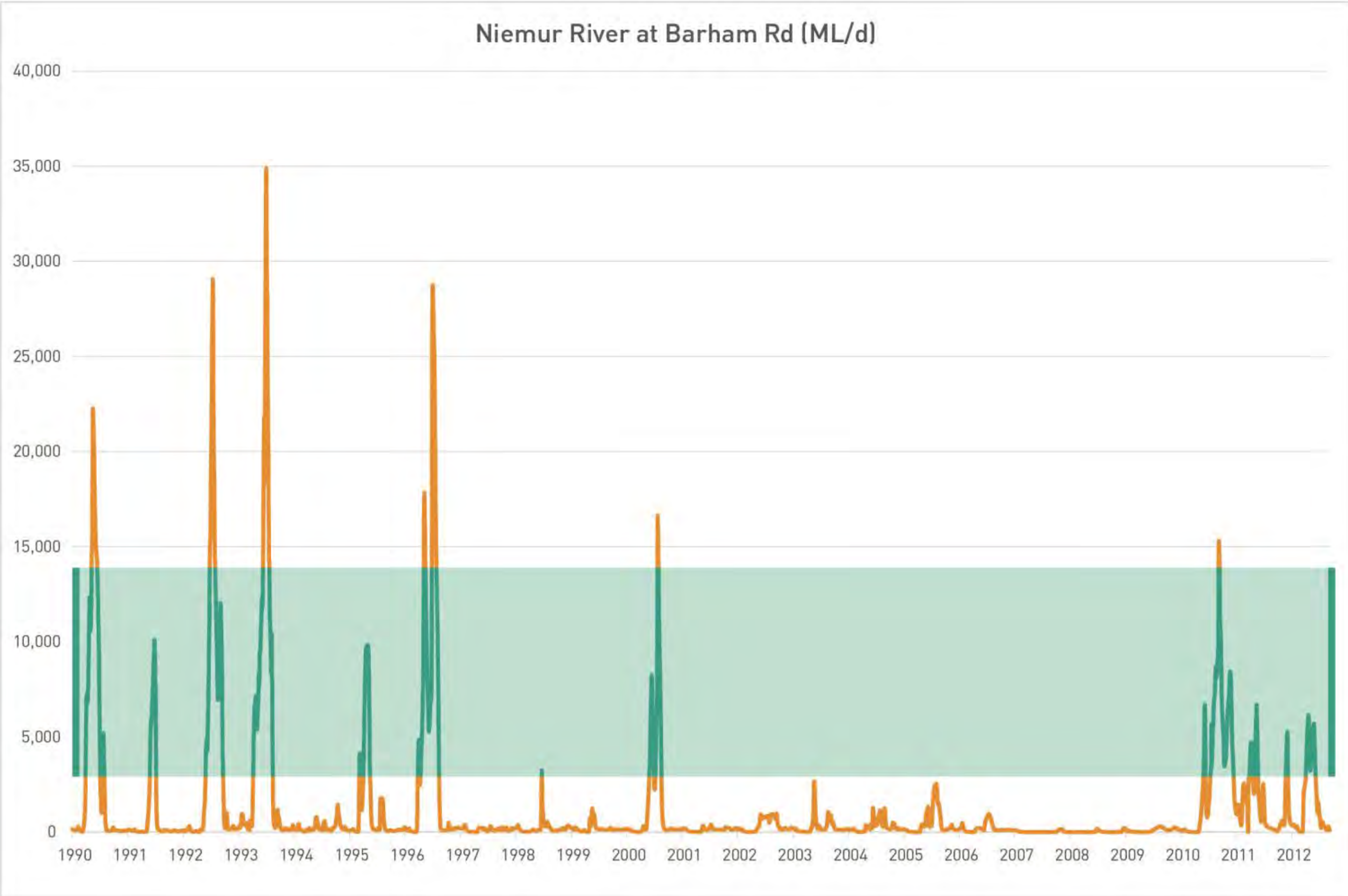


Figure 20. Average daily water flow in the Niemur Riverat Barham Rd (gauging station 409048), January 1990 – December 2012

Appendix 2 Potential effects on townships within the reach

Table 5: Potential effects recorded for townships within the Yarrawonga Weir to Wakool Junction reach.

Gauge and flood level	Location	Flow rates investigated based on Tocumwal gauge			
		Up to 20,000 ML/day (3.52 m)[a]	20,000 - 35,000 ML/day (4.78 m)[a]	35,000 - 50,000 ML/day (5.7 m)[a]	50,000 - 77,000 ML/day (6.4 m)[a]
Yarrawonga gauge Min – 6.4m Mod – 6.7m Maj – 7.8m		22,000[b] (3.0 m)	36,000[b] (4.2 m)	52,000[b] (5.2 m)	82,000[b] (6.4 m)
	Yarrawonga	No effects reported	No effects reported	No effects reported	Local golf course affected at flows 68,000[b] ML/day at Yarrawonga[7]
	Cobram[8]	No effects reported	No effects reported	No effects reported	No effects reported
Tocumwal gauge Min – 6.4m Mod – 6.7m Maj – 7.3m		20,000 (3.52 m)a	35,000 (4.78 m)a	50,000 (5.7 m)a	77,000 (6.4 m)
	Tocumwal[9]	Access to Tocumwal Beach boat ramp closed	Carpark near pontoon closed Town stormwater drains closed Close Barooga Cowl drainage gate	Town Beach Rd closed	Lower River Rd causeways running Access Rd closed — Bushlands Caravan Park

[7] VICSES 2013.

[8] VICSES 2013.

[9] CMS meetings with Berrigan Shire Council in 2013 and 2014.

Gauge and flood level	Location	Flow rates investigated based on Tocumwal gauge			
		Up to 20,000 ML/day (3.52 m)[a]	20,000 - 35,000 ML/day (4.78 m)[a]	35,000 - 50,000 ML/day (5.7 m)[a]	50,000 - 77,000 ML/day (6.4 m)[a]
Barmah gauge Min – 6.0m Mod – 6.5m Maj – 7.0m		11,000 (3.35 m)	20,000 (5.02 m)	29,000 (6.38 m)	35,000 (6.81 m)
	Barmah[10]	Not assessed	Not assessed	Potential effects Additional analysis required	Potential effects at Barmah Caravan Park Levee network provides protection to 30-year ARI event
Echuca gauge (m AHD) Min – 93.5 Mod – 93.9 Maj – 94.4					
	Echuca[11]	No effects reported	No effects reported	River boat operations ceased during 2010 (Torrumbarry was 7.66 m)	NCCMA to advise of potential effects on new residential development
	Moama[12]	No effects reported	No effects reported	No effects reported	RiM-FIM modelling shows lower areas of 2 x caravan parks in Moama being affected (60-64,000 ML/day Echuca).

[10] VICSES 2013.

[11] CMS meeting with North Central CMA in September 2014.

[12] CMS meetings with Murray Shire Council in 2013 and 2014.

Gauge and flood level	Location	Flow rates investigated based on Tocumwal gauge			
		Up to 20,000 ML/day (3.52 m)[a]	20,000 - 35,000 ML/day (4.78 m)[a]	35,000 - 50,000 ML/day (5.7 m)[a]	50,000 - 77,000 ML/day (6.4 m)[a]
Barham gauge Min – 5 5 m Mod – 5.8 m Maj – 6.1 m		22,000 (5.52 m)	25,000 (5.81 m)	28,000 (5.99 m)	35,000 (6.18 m)
	Barham[13]	No effects reported	No effects reported	No effects reported 1 in 5-year ARI modelled as 28,400 ML/day	No effects reported unless levee failure occurs 1 in 50-year ARI modelled as 34,900 ML/day
	Koondrook[14]	No effects reported	No effects reported	No effects reported	No effects reported
	Murrabit[15]	No effects reported	No effects reported	No effects reported	No effects reported Township relies on River Murray levee. NB difficult to use historic flow/flood information due to extensive new development on NSW side of River Murray

[13] GHD 2014b.

[14] CMS meeting with North Central CMA in September 2014.

[15] CMS meeting with North Central CMA in September 2014.

Gauge and flood level	Location	Flow rates investigated based on Tocumwal gauge			
		Up to 20,000 ML/day (3.52 m)[a]	20,000 - 35,000 ML/day (4.78 m)[a]	35,000 - 50,000 ML/day (5.7 m)[a]	50,000 - 77,000 ML/day (6.4 m)[a]
Swan Hill gauge Min – 4.5m Mod – 4.6m Maj – 4.7m		20,000 (3.38 m)	24,000 (3.94 m)	25,000 (4.07 m)	32,000 (4.68 m)
	Swan Hill[16]	No effects reported	No effects reported	No effects reported 1 in 2-year ARI modelled as 25,700 ML/day	Potential effects on low-lying parts of town caravan and 'riverside' park 1 in 20-year ARI modelled as 32,600 ML/day
	Murray Downs[17]	No effects reported	No effects reported	No effects reported 1 in 2-year ARI modelled as 25,700 ML/day	No effects reported 1 in 20-year ARI modelled as 32,600 ML/day
	Tooleybuc[18]	No effects reported	No effects reported	No effects reported 1 in 2-year ARI modelled as 25,700 ML/d	No effects reported 1 in 20-year ARI modelled as 32,600 ML/day

[16] GHD 2014a.

[17] GHD 2014a.

[18] GHD 2014c.

Gauge and flood level	Location	Flow rates investigated based on Tocumwal gauge			
		Up to 20,000 ML/day (3.52 m)[a]	20,000 - 35,000 ML/day (4.78 m)[a]	35,000 - 50,000 ML/day (5.7 m)[a]	50,000 - 77,000 ML/day (6.4 m)[a]
Deniliquin gauge Min – 4.6m Mod – 7.2m Maj – 9.4m		7,500 (n/a)[b]	14,000[b] (4.2 m)	23,000[b] (5.22 m)	48,000[b] (7.12 m)
	Deniliquin[19,20]	No effects reported	Close golfcourse flood gate (3.9m) Relocate McLean's Beach toilet (mobile) if forecast height >4.5 m (3.9 m)	Walk bridges closed at 4.3–4.6 m Water enters Island Sanctuary Reserve (4.66 m) Close Butler St pipe under levee (5.0 m)	Evacuate McLean's Beach Caravan Park (5.7 m) Close Butler St gate valve (5.7 m) McLean Beach Sewer pump station inundated (5.84 m) Close Wyatt St levee outlet (6.4 m) Close Crispe St gate valve (near Deni Car-O-Tel) (6.88 m) Close Crispe St gate valve (behind Middy's) (6.96 m)
Moulamein gauge *Min –4.6* *Mod –5.2* *Maj – 6.1*		5,000[b] (3.5 m)	7,000[b] (4.1 m)	8,000[b] (4.5 m)	17,000[b] (5.5 m)
	Moulamein	No effects reported	No effects reported	No effects reported	No effects reported

Source: Data were collected from flood studies and discussions with local councils between 2013 and 2014.

a Flow rates were based on the Tocumwal gauge and were the basis for the RiM-FIM modelling.

b Flow rates were estimated by correlation of historic flows using average travel time. Data for these gauges were not used in the development of inundation maps but have been provided to assist interpretation of the flows being studied.

---

[19] CMS meetings with Deniliquin Council in 2013 and 2014.

[20] WMA Water 2014.

Appendix 3 Key issues register

Table 6 provides a summary of key issues and how it is proposed to addressed them, at the time of publication. Some of these matters may take time to resolve, and additional matters may arise. Unresolved matters will continue to be addressed through Feasibility and/or Implementation phases.

Table 6. Register of key issues identified through community consultation during 2013-14.

Issue	Steps to resolve
Increased risk of uncontrolled flood events	Study proposed for 2015 involving the community that develops ways to better understand the potential for increased flood risk and investigate how increased regulated flows might be delivered in ways that minimise risk
Competition for channel share	Competition for channel share was investigated through the operational and management constraints process and reported on in the CMS Annual Progress Report 2014. It was found that environmental water is unlikely to increase, and may even decrease competition for channel share.
Interrupted or impeded access to land	Private agriculture/public infrastructure case studies proposed for 2015
Overland flooding significantly altering current land activity	Private agriculture case studies proposed for 2015
Floodplain management planning — may limit activities in floodways	Developing a project to understand the impact on levees and implications for any potential mitigation options for Floodplains (see levee comments below)
Frequency, timing, duration and predictablity of proposed flows — critical to understanding effects	Further modelling being refined in 2015
Managing access during emergencies — bushfires	Understand how risk is currently managed by community. Water delivery in winter or spring is unlikely to coincide with periods of high fire risk. However, there may be some overlap during summer or early autumn.
Potential for environmental damage — pest species, erosion, tree loss, salinity, acid sulfate soils, blackwater and siltation/sedimentation	Management of these risks through existing programs. If higher managed flows were to be implemented, they would be delivered by slowly increasing rates of managed events over time, allowing feedback from existing programs.

Issue	Steps to resolve
Groundwater recharge — increased salinity risk	Management of these risks through existing programs. If higher managed flows were to be implemented, they would be implemented gradually over time, allowing feedback from existing programs.
Devaluation of private land asset	Private agriculture case studies proposed for 2015
Public and private infrastructure — effects on bridges, buildings and pumps	Public infrastructure and private agriculture case studies proposed for 2015
Tourism — frustrated river access, uncertainty in holiday planning, increased exposure to mosquitoes and sandflies	Public infrastructure and specialist activities case studies proposed for 2015
Adequacy of funding — dividing community, transparency and clarity of processes	There is $200 million available by the Commonwealth to address constraints. The application of those funds, if Constraints Management proceeds to implementation, will be through fair, transparent and equitable principles.
Environmental watering events and benefits — improved communication.	Collective governments to improve communication of environmental watering through experience over time.
Redgum regrowth in channel – restricting flows	If higher managed flows were to be implemented, they would be delivered by slowly increasing flow rates in different events over time. This allows for changes in channel capacity to be taken into account.
Clarify who carries liability for third party impacts	Further investigation by governments through 2015 and beyond.
Levees – how they are affected, responsibility for maintenance and new levees in floodway	Understand which levees will be affected by flows being examined. Understand the design objectives and current maintenance standard of those levees and assess the ability of levees to withstand the potential flow regime. Understand current floodplain legislative and planning constraints.
Private diverter access - changes in water demand patterns (through the Basin Plan) alter river flows, will this affect water access	Continue to work with River Operators and partner governments throughout feasibility to further understand this issue.
Undertake trials of smaller events to build trust	Continue to work with River Operators and Environmental Water holders throughout feasibility to further progress this concept.

References

BOM (Bureau of Meteorology) 2014, *Flood warning services*, BOM, Melbourne, www.bom.gov.au/water/floods/floodWarningServices.shtml, viewed 28 August 2014.

Cunningham, SC, White, M, Griffioen, P, Newell, G & Mac Nally, R 2013, *Mapping floodplain vegetation types across the Murray–Darling Basin using remote sensing*, Murray–Darling Basin Authority, Canberra.

Davies, PE, Harris, JH, Hillman, TJ & Walker, KF 2008, *SRA report 1: Report by the Independent Sustainable Rivers Audit Group to the Murray–Darling Basin Ministerial Council,* MDBC publication no. 16/08, Murray–Darling Basin Commission, Canberra.

Davies, PE, Stewardson, MJ, Hillman, TJ, Roberts, JR & Thoms, MC 2012, *Sustainable Rivers Audit 2: The ecological health of rivers in the Murray–Darling Basin at the end of the millennium drought (2008–2010)*, volume 3, Murray–Darling Basin Authority, Canberra.

DECCW (Department of Environment, Climate Change and Water NSW) 2010, *State of the catchments: native vegetation — Murray region*, DECCW, Sydney.

DECCW (Department of Environment, Climate Change and Water NSW) 2011a, *Floodplain Management Plan: Edward and Wakool Rivers Stage 1, Deniliquin to Moama-Moulamein Railway*, DECCW, Sydney.

DECCW (Department of Environment, Climate Change and Water NSW) 2011b, *Floodplain Management Plan: Wakool River Stage 2, Moama-Moulamein Railway to Gee Gee Bridge*, DECCW, Sydney.

DECCW (Department of Environment, Climate Change and Water NSW) 2011c, *Floodplain Management Plan: Edward and Niemur Rivers Stage 3, Moama-Moulamein Railway to Liewah and Mallan*, DECCW, Sydney.

DLWC (NSW Department of Land and Water Conservation) 2000, *Edward and Wakool rivers floodplain management strategy: Noorong Road to Wakool Murray Junction (Stage IV),* DLWC, Sydney.

DNR (NSW Department of Natural Resources) 2004, *Tuppal and Bullatale creeks floodplain management plan*, DNR, Sydney.

DPI (NSW Department of Primary Industries) 2007, *Endangered ecological communities in NSW: Lower Murray River aquatic ecological community*, Primefact 172, 2nd edition, DPI, Sydney.

DPI (NSW Department of Primary Industries) 2008, *The assessment and prioritisation of barriers to fish passage in the Murray Catchment: report to the Murray Catchment Management Authority,* Conservation Action Unit, DPI, Albury.

DPI (NSW Department of Primary Industries) 2014, *Barmah Millewa controlled flow release 2013 — report on stakeholder engagement*, Office of Water, DPI, Deniliquin.

FSC (Fisheries Scientific Committee) 2002, *Aquatic ecological community in the natural drainage system of the lower Murray River catchment*, ref. no. FR16(2), file no. FSC 01/01, FSC, Sydney, www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/208295/FR16-Murray-River-EEC.pdf, viewed 10 July 2014.

Gilligan, D, Vey, A & Asmus, M 2009, *Identifying drought refuges in the Wakool system and assessing status of fish populations and water quality before, during and after the provision of* *environmental, stock and domestic flows.* NSW Department of Primary Industries, Batemans Bay.

Green, D 2001, *The Edward–Wakool system: river regulation and environmental flows*, NSW Department of Land and Water Conservation, Murray Region, Deniliquin.

Green, D, & Alexander, P 2006, *River Murray Wetlands Database — NSW, Victoria, wetland commence to flow levels: June 2006*, NSW Murray Wetlands Working Group, Albury.

GHD 2009, *NSW Central Murray State Forests: draft ecological character description*, Forests NSW, 21/17430/141656, GHD Australia, Sydney.

GHD 2014a, *Wakool Shire Council: Murray Downs flood study, draft final report*, GHD, Wodonga.

GHD 2014b, *Wakool Shire Council: Barham flood study, draft final report*, GHD, Wodonga.

GHD 2014c, *Wakool Shire Council: Tooleybuc flood study, draft final report*, GHD, Wodonga.

Koehn, J 1996, *Habitats and movements of freshwater fish in the Murray–Darling Basin*, Riverine Environment Research Forum, Murray–Darling Basin Commission, Canberra.

Lintermans, M 2007, *Fishes of the Murray–Darling Basin, an introductory guide*, Murray–Darling Basin Commission, Canberra.

Maunsell Australia 2009, *Floodplain risk management study: Edward, Wakool and Niemur rivers — stages 1, 2 and 3 for Department of Environment & Climate Change NSW*, Maunsell Australia, Melbourne.

MCMA (Murray Catchment Management Authority) 2012a, *Alternate downstream flow options preliminary community engagement: report to the Murray–Darling Basin Authority*, MCMA, Deniliquin.

MCMA (Murray Catchment Management Authority) 2012b, *Deliverability of environmental water in the Murray Valley: report to Murray group of concerned communities*, MCMA, Deniliquin.

MDBA (Murray–Darling Basin Authority) 2011, *Timeseries computer model data for proposed Basin Plan*. MDBA, Canberra.

MDBC (Murray–Darling Basin Commission) 2001, *Rivers as ecological systems: the Murray–Darling Basin*, MDBC, Canberra.

Murray Now 2014, *Murray Now it's the place: regional profile 2013–14*, Murray Now, http://murraynow.com.au/murray-region-regional-profiles/murray-now-regional-profile-2012/, viewed 28 August 2014.

NRC (Natural Resources Commission) 2009, *Riverina bioregion regional forest assessment: river red gums and woodland forests*, NRC, Sydney.

OEH (NSW Office of Environment and Heritage) 2014a, *Murray and Lower Darling valleys environmental water updates: Cockran, Jimaringle and Gwynnes creek systems,* OEH, Sydney, www.environment.nsw.gov.au/environmentalwater/envwatermurraylowerdarlingupdate.htm, viewed 28 August 2014.

OEH (NSW Office of Environment and Heritage) 2014b, *Environmental water use in New South Wales: outcomes 2012–2013*, OEH, Sydney.

SMEC 2003, *Edward/Wakool rivers, stages 1, 2, 3 rural floodplain management plan: phase a compendium of data*, SMEC and Brian Mitsch and Associates.

Thoms, MS, Suter, P, Roberts, J, Koehn, J, Jones, G, Hillman, T & Close, A 2000, *Report on the River Murray Scientific Panel on Environmental Flows. River Murray – Dartmouth to Wellington and the Lower Darling River,* Murray–Darling Basin Commission, Canberra.

Tyler, M 2009, *Field guide to the frogs of Australia*, CSIRO Publishing, Collingwood.

VICSES (Victorian State Emergency Service) 2013, *Moira Shire Flood Emergency Plan: a sub-plan of the municipal emergency management plan*, VICSES, Melbourne.

Wang, B, Khan, S, O'Connell, N 2003, *Quantifying impact of rainfall on shallow groundwater table In the Wakool irrigation district, NSW,* CSIRO Land and Water, Griffith Laboratory, Griffith.

Watts, RJ, Kopf, RK, Hladyz, S, Grace, M, Thompson, R, McCasker, N, Wassens, S, Howitt, JA & Conallin, J 2012, *Monitoring of ecosystem responses to the delivery of environmental water in the Edward–Wakool river system, 2011–2012*, report 1 prepared for the Commonwealth Environmental Water Office, Institute for Land, Water and Society, Charles Sturt University.

WMA Water 2014, *Edward River at Deniliquin flood study: final draft for public exhibition*, WMA Water, Sydney.

Ye, Q, Giatas, GC, Aldridge, KT, Benger, SN, Bice, CM, Brookes, JD, Bucater, LB, Cheshire, KJM, Cummings, CR, Doody, TM, Fairweather, PG, Frahn, KA, Fredberg, JF, Gehrig, SL, Holland, KL, Leigh, SL, Lester, RE, Lorenz, Z, Marsland, KB, Nicol, JM, Oliver, RL, Overton, IC, Pritchard, JL, Strawbridge, AD, Thwaites, LA, Turnadge, CJ, Wilson, PK & Zampatti BP 2014, *Ecological responses to flooding in the lower River Murray following an extended drought*, synthesis report of the Murray Flood Ecology Project, Technical Report Series No. 14/6, Goyder Institute for Water Research, Adelaide.